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Irina-Emily Hansen

Industry-Academia Collaboration in Research and Innovation Projects - *A Knowledge Management Perspective*

Doctoral thesis

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FREFACE

The thesis has been submitted to the Department of Mechanical and Industrial Engineering and the Department of Ocean Operations and Civil Engineering at the Norwegian University of Science and Technology (NTNU). The project began on 1st of September 2016 and was completed on 31st of August 2021. The work was supervised by Professor Torgeir Welo (main supervisor) and Professor Ola Jon Mork (co-supervisor).

The thesis is paper-based, meaning that the core of the thesis is a series of scientific papers published in peer-reviewed conference proceedings and published and/or submitted to peer-reviewed journals. The thesis is based on five conference publications and one journal paper. All the conferences and the journal are recognised by the Norwegian Register for Scientific Journals, Series, and Publishers.

Because the research work was started with the intention to improve the university's collaboration with the industry, the words 'university' and 'university-industry collaboration' were used in all five conference papers. However, the research work is related to innovation projects in the industry where both universities and research institutions are involved. Therefore, the entire study covers industry-academia collaboration. Consequently, the last (journal) paper and the thesis refer to industry-academia research and innovation projects.

Meetings with experts around the world have profoundly broadened my perspectives on the studied subject. Visiting incubators for start-ups and universities in Singapore and interviewing the researchers at Nottingham University and the scientists from the Manufacturing Catapult Technology Centre in the UK, Coventry, gave me some great insights on how other countries approach industry-academia collaboration in research and innovation. I have also joined the international University-Industry Innovation Network and participated in the network 'Creating strategic industry partnership' course. In addition, participation in conferences worldwide opened the possibility of exchanging knowledge with other researchers. These experiences have enriched my research work and allowed me to grow personally and professionally as an academic.

Aalesund, Norway, July 1st, 2021

Irina-Emily Hansen

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I would like to thank the people who have helped me to conduct this thesis.

Foremost, I would like to thank my supervisor, Torgeir Welo, for providing guidance and feedback throughout this scientific work, for the challenges and consistent support, he gave me on a way of developing me as a researcher.

I want to extend my profound gratitude to co-advisor professor Ola Jon Mork. For believing in me, motivating me, and helping me to stay on track. For knowing when to push, and when to give space in my research work. His insights and knowledge into the subject matter have contributed a lot to the thesis.

A special thanks to Lars Andre Giske, for being exceptionally motivating and supportive. As the industrial Ph.D., he was in the center of the 'battlefield' of my study. By generously sharing information and providing insight, he has brought lots of valuable knowledge to the thesis.

I would also like to thank the co-author of one of the papers, Geir Ringen, for contributing with his expertise in data analysis and in the field of my Ph.D. study.

I would love to thank my colleagues at university and research institutions for all their help and valuable support, for giving constructive feedback and recommendations.

Many thanks to the pall participants that took part in the study and enabled this research to be possible - all the industrial and academic project leaders, Ph.D. students who agreed to be interviewed, and who took the time to complete the questionnaire and contributed so thoroughly to the research through their comments.

I cannot forget to thank my family and friends for all the unconditional support during this very intense and great Ph.D. journey. It means the world to me.

LIST OF PUBLICATIONS

The following gives an overview of the publication outputs of the PhD project. As shown, the project resulted in five conference papers and one journal paper.

Main papers of the thesis
Main paper 1: Hansen, I. E., Mork, O. J., & Welo, T. (2017)
Knowledge management of university-industry collaboration in the learning economy.
Proceedings of 2017 2nd International Conference on Knowledge Engineering and Applications (ICKEA)

Main paper 2: Hansen, I. E., Mork, O. J., & Welo, T. (2019)
Managing Knowledge in Manufacturing Industry - University Innovation Projects.
Proceedings of IFIP Advances in Information and Communication Technology

Main paper 3: Hansen, I. E., Mork, O. J., Welo, T. & Ringen, G. (2021)
Bridging the 'Valley of Death': Can Agile Principles Be Applied in Industry-Academia Research and Innovation Projects?
Journal of the Knowledge Economy.

Supportive papers for the thesis
Supportive paper 1: Hansen, I.-E., Mork, O. J., & Welo, T. (2018)
Towards a framework for managing knowledge integration in university-industry collaboration projects.
Proceedings of the European Conference on Knowledge Management, ECKM

Supportive paper 2: Hansen, I. E., Mork, O. J., & Welo, T. (2019)
Exploring framework for university-industry innovation projects: Building collaborative knowledge platform.
Proceedings of the European Conference on Knowledge Management, ECKM

Supportive paper 3: Hansen, I.-E., Mork, O. J., Welo, T., & Giske, L. A. L. (2019)
University-Industry Collaboration Projects: A Case of Norway.
Proceedings of ICICKM 2019 16th International Conference on Intellectual Capital Knowledge Management & Organisational Learning

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SUMMARY

Industry-academia (I-A) research and innovation (R&I) projects often fail to transform research results into successful outcomes in industrial settings. Industrial and academic organisations differ in regard to culture, time schedules and goals. In general, an industrial organisation has to be strongly committed to daily operations, customers' immediate needs, and cash flow, while an academic organisation usually focuses on the creation of long-term knowledge and academic research. Industrial companies, academia, and society in general will benefit from a successful transformation of research outcomes into successful innovations and new value creation. This thesis concerns the understanding of lack of transparency—the gap, or the so-called 'valley of death'—in cases where collaborative projects fail to realise research results derived from collaborative projects.

Up to now, studies on innovation success from I-A collaboration have mainly concentrated on academic engagement, number of patents, spill-overs and publications or institutional set-ups. Meanwhile, the nature of true innovation—the creation of knowledge that ultimately leads to new value for products or the processes employed to produce them—has been ignored. Careful and deliberate nurturing the knowledge-creation processes is essential for innovation success. Therefore, this thesis aims to define a conceptual knowledge management (KM) model for I-A R&I projects. To achieve the research objective, three research questions are defined:

RQ1: What are the critical factors in I-A R&I projects, and how should the KM model address them?

RQ2: How can the Nonaka & Takeuchi KM model address the identified critical factors for I-A R&I projects?

RQ3: How can agile principles be used to support the KM model for I-A R&I projects?

To answer the first research questions, a literature review seeking evidence on (best-)practices in collaborative I-A innovation projects was conducted. This literature review helped identifying the critical factors for success in this type of projects. The identified critical factors constitute the first contribution to the study (C1). These factors imply the definition of I-A collaborative strategies and objectives, facilitation of collaboration, and learning from the projects. To obtain the knowledge perspective on the critical factors, we refer to the KM literature, which supports the identification of the requirements of the KM model for it to reinforce I-A collaboration in R&I projects. The requirements constitute the second contribution to the study (C2).

When we studied RQ2 and RQ3, we focused on innovation projects in the industry, abbreviated as IPN (innovation projects for business) in Norway. The study concentrated mainly on innovation projects conducted in the manufacturing sector.

To answer RQ2, we conducted qualitative research focusing on critical factors and the requirements for the KM model. The data for RQ2 was collected from interviews, observations, project reports and workshops. The obtained data were categorised and ultimately resulted in the dynamic conceptual KM model for I-A R&I projects. The model provides three additional contributions to the study. First, it incorporates the KM model of Nonaka and Takeuchi in three interdependent levels:

strategic level of industry and academia separately, collaborative I-A strategic level, and I-A project level (C3). The second contribution is the collaborative concept at each of the three levels. The concepts consist of the management practices that address the critical factors (C4). *Knowledge exploiting* expands the I-A knowledge-creation process and constitutes the next contribution (C5).

Since management practices appeared to show similarities with the agile principles, we initiated a study on the potential use of the agile principles as guidelines for I-A R&I projects. We surveyed 124 IPN leaders (70 from the industry; 54 from academia) to evaluate the importance of the KM practices associated with the six agile principles across the three project stages. The statistical analyses indicate the consistency of the agile principles throughout the project stages (C7). This means that the agile principles are found relevant to the IPNs and can be used as guidelines for improving KM practices. Moreover, the study identifies the agile principles that are perceived as essential in the different stages of a project (C8). It also identifies the perceptions of the importance of agile principles of different project leaders from the industry and academia (C9). These findings can support project leaders who are implementing agile principles in I-A R&I projects.

Overall, the study contributes to the three scientific fields. The study proposes the conceptual KM model for I-A R&I projects, which integrated the Nonaka and Takeuchi KM model with the three modifications. Subsequently, the study shows that the use of the proposed conceptual KM model and the agile principles can potentially be a practical tool for KM of I-A R&I projects. This means that the Nonaka and Takeuchi KM model, together with the agile principles, can enable innovation in I-A R&I projects and contribute to bridging the 'valley of death'. The results from this study can also support national and federal research/innovation councils in decision making when assessing industrial research applications.

CONTENT

1. INTRODUCTION

1.1 BACKGROUND

Continuous long-term collaboration between industry and academia in research and innovation (R&I) drives global economic and social growth. To further boost innovation in the private sector, governments aim to share the risk of innovation by providing economic support to industry-academia (I-A) R&I projects. Nevertheless, many of the great results derived from collaborative projects fall into the so-called 'valley of death', the (technological) gap between academic research and industrial implementation (S. Ankrah & AL-Tabbaa, 2015; Clauss & Kesting, 2017; Maietta, 2015; Maughan et al., 2013). This implies a missed opportunity for the economic and social development of companies and the society. One of the main reasons for this failure is the fundamental difference between industry and academia. Despite many mutual benefits from collaboration, the actors in such public private projects lean on different governing variables, e.g., academic publishing versus industrial commercialisation, and have a different pace in providing results (Bellini et al., 2019; Perkmann et al., 2021). Therefore, it is essential to find management approaches to facilitate I-A collaboration ultimately leading to innovation success (B. T. Asheim, 2019; *European Commission*, n.d.; Carayannis & Campbell, 2012; OECD, 2019; Sjoer et al., 2016).

The first section of this thesis presents a literature study aimed at identifying the state-of-the-art in I-A collaboration in R&I projects. The findings show that most of the studies in this field have so far concentrated on project inputs—such as partners' motivation to collaborate—and projects outputs—such as numbers of patents and articles published (Ankrah & AL-Tabbaa, 2015; Bazan, 2019; Bellini et al., 2019; Laine et al., 2015; Perkmann et al., 2021). However, the key fact that innovation is a practical application of knowledge has been left out. Knowledge creation is the core of innovation, and the effective management of knowledge enables organisations to extract more innovation potential (Amabile, 1988; Chesbrough & Bogers, 2014a; Kanter, 2000; Salter et al., 2014). Therefore, this thesis aims to find an appropriate knowledge approach to managing I-A R&I projects.

There are many types of R&I projects which involve collaboration between industry and academics, e.g., public private partnerships (PPPs) in the EU community. We have chosen one common type of projects in Norway, so-called innovation projects in the business or industrial sector (abbreviated as IPN). Nearly half of the IPNs report innovation success (Bjørn G. Bergem, 2019) in terms of criteria established by the Research Council of Norway. The IPNs are governmentally supported research-based innovation projects between industry and academia, where the latter is typically a university or research institution. The contract is between the Research Council of Norway (RCN) and the industrial company. Moreover, the academic institution is contracted to perform the research with the industrial company. The industry initiates the IPN and finances typically 60% of the total project costs, mainly through in-kind hours assigned to the project. The RCN covers the costs related to the research activities of the academic project partners. An IPN typically lasts three to four years and has an average total budget of 1.5 million EUR (*The Research Council of Norway. Innovation projects in industrial sector*, n.d.).

In this study, IPNs were chosen based on the following conditions:

- The company partner operates within the manufacturing industry.
- The project was conducted during the period 2011-2019.
- In case of ongoing projects, at least half the project period has been reached.

It is important to emphasise that applied research is typical for this type of projects (B. Asheim & Grillitsch, 2015; B. T. Asheim, 2019; Narula, 2004; Solheim & Stølen, 2007). Applied research often seeks solutions to practical problems, which is different from basic research aiming to obtain new knowledge (Manual, 2002).

There are different definitions of knowledge management (KM) in the literature. In this thesis, the definition of KM refers to the most cited publications of O'dell and Grayson (1998), as well as Daventport and Prusak (1998):

- *KM is, therefore, a conscious strategy of getting the right knowledge to the right people at the right time and helping people share and put information into action in ways that strive to improve organisational performance* (O'dell & Grayson, 1998).
- *KM draws from existing resources that your organisation may already have in place—good information systems management, organisational change management, and human resources management practices* (Davenport & Prusak, 1998).

Because the research work was started with the intention to increase the understanding of the university and industry collaborative projects, the words 'university' and 'university-industry collaboration' were used in all the papers, except for the last one. However, the research work relating to IPNs where both universities and research institutions are involved and have complementary roles. Therefore, the entire PhD study covers I-A collaboration.

1.2 OBJECTIVE AND RESEARCH QUESTIONS

The research objective (RO) of this thesis, is to establish a conceptual KM model for I-A R&I projects**.** Facing the *valley of death*, KM of the I-A and R&I projects should focus on the aspects that help close the technological gap. Therefore, the first research question **(RQ1)** is: **What are the critical factors in I-A R&I projects and how should the KM model address them?**

Answers on RQ1 brought attention to the Nonaka and Takeuchi KM model (Ikujiro Nonaka & Takeuchi, 1995). Their model has the potential to address the identified critical factors. However, the Nonaka and Takeuchi KM model concerns knowledge creation between business organisations, not between the industry and academia. Therefore, the second research question **(RQ2)** is: **How can the Nonaka & Takeuchi KM model address the identified critical factors for I-A R&I projects?**

The findings related to RQ2 reveal that the Nonaka and Takeuchi KM model, with three modifications, is applicable to I-A and R&I projects. The Nonaka and Takeuchi model is acknowledged as one of the most robust in the field of KM. However, it does not cover how decision-making takes place when managing transformations between tacit and explicit knowledge (Dalkir, 2017). Meanwhile, the results of RQ2 identified the management practices that have much in common with the agile principles from agile project management (APM). Since APM uses agile principles as guidelines to improve management practices, whether these can serve as guidelines to improve management practices in I-A R&I projects need to be investigated. Thus, the third research question **(RQ3)** is: **How can agile principles be used to support the KM model for I-A R&I projects?**

Table 1 gives an overview of the thesis-specific research questions and the contributions of the main papers.

Table 1. Contribution of the main papers to answering the thesis-specific research questions

Paper 1: Knowledge Management of University Industry Collaboration in the Learning Economy	
RQ1: What are the critical factors in I-A research and innovation projects and how KM model should address them?	**C1.** The study identifies the critical factors that KM should address in innovation in I-A R&I projects. The critical factors are the definition of a long-term strategy and the project objectives, facilitation of projects and acceleration of learning from the project. **C2.** Requirements to the KM model to address the CF in I-A R&I projects: - Knowledge perspective in defining of strategies and objectives. - Conversion between tacit and explicit knowledge, - Combination of scientific (STI) and practical (DUI) modes of innovation. - Continuous integration of new knowledge in organizations.
Paper 2. Managing Knowledge in Manufacturing Industry - University Innovation Projects	
RQ2: How Nonaka & Takeuchi KM model can address the critical factors in the KM model for I-A R&I projects?	**C3.** KM model for I-A R&I projects integrates Nonaka &Takeuchi KM model in three inter-dependent levels: - Each organization's strategic level (separately for industry and academia). - I-A collaborative strategic level. - I-A project level. **C4.** The collaborative concepts in KM model for I-A R&I projects consist of the management practices that address the critical factors in these projects. **C5.** Continuous knowledge exploiting in all three levels improves the collaborative concepts and integrates dynamic into the KM model for I-A R&I projects.
Paper 3. Bridging the 'Valley of Death': Can Agile Principles be Used in Industry – Academia Research and Innovation Projects?	
RQ3: How can agile principles be used to support KM model for I-A R&I projects**?**	**C6**: The agile principles are consistent with the management practices related to use of the Nonaka and Takeuchi KM model in I-A R&I projects. The consistency shows that the agile principles have a potential to be used as guidelines for improvement of the management practices in the KM model for I-A R&I projects. **C7**: The perceived importance of the agile principles by the project leaders identifies the peculiarities of the agile principles' use in I-A R&I projects. Use of the agile principles 'Iterative & incremental learning', 'Flexibility' and 'Reflective actions' in the execution stages triggers use of these principles in the planning and the evaluation stages. Use of the 'Reflective actions' in any of project stages triggers use of this principle in any other stage. **C8**: Industry and academia have differences in perception of the importance of the agile principles in I-A R&I projects. The principle 'Enabling environment' in the project planning and the evaluation stages, as well as 'Flexibility' and 'Collaboration' in the execution stage show to be perceived as more important by industry than by academia.

The remainder of this thesis is organised as follows: Section 2 introduces the theoretical scope and the knowledge gaps in the respective scientific fields. Section 3 presents the methodology, including studies and validation methods. In Section 4, contributions related to the research questions, the limitations of the study, and future research are discussed. Section 5 presents the conclusions.

1.3 SCOPE

Fig 1 shows that the thesis falls into the intersection area between three scientific fields. The RO is in the field of I-A collaboration in R&I. While the KM field, together with APM, support in achieving the study's objective and answering the research questions.

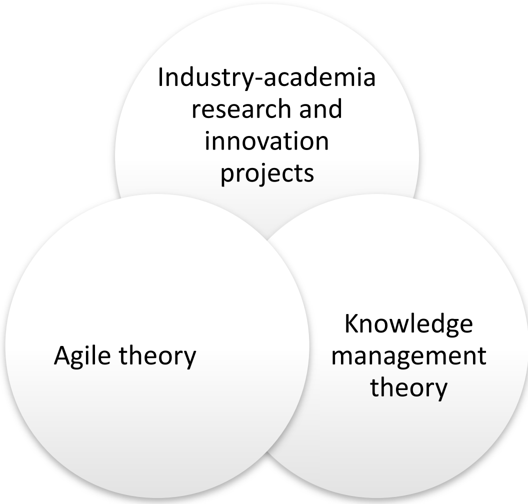

Fig 1. Analytical model of the main field of this thesis

Fig 2 illustrates how research fields become interconnected during the study. Fig 2 shows the main papers with the knowledge gaps, corresponding thesis-specific research questions, and the contributions. The following describes the state-of-the art and gaps in the knowledge fields being studied and calling for research.

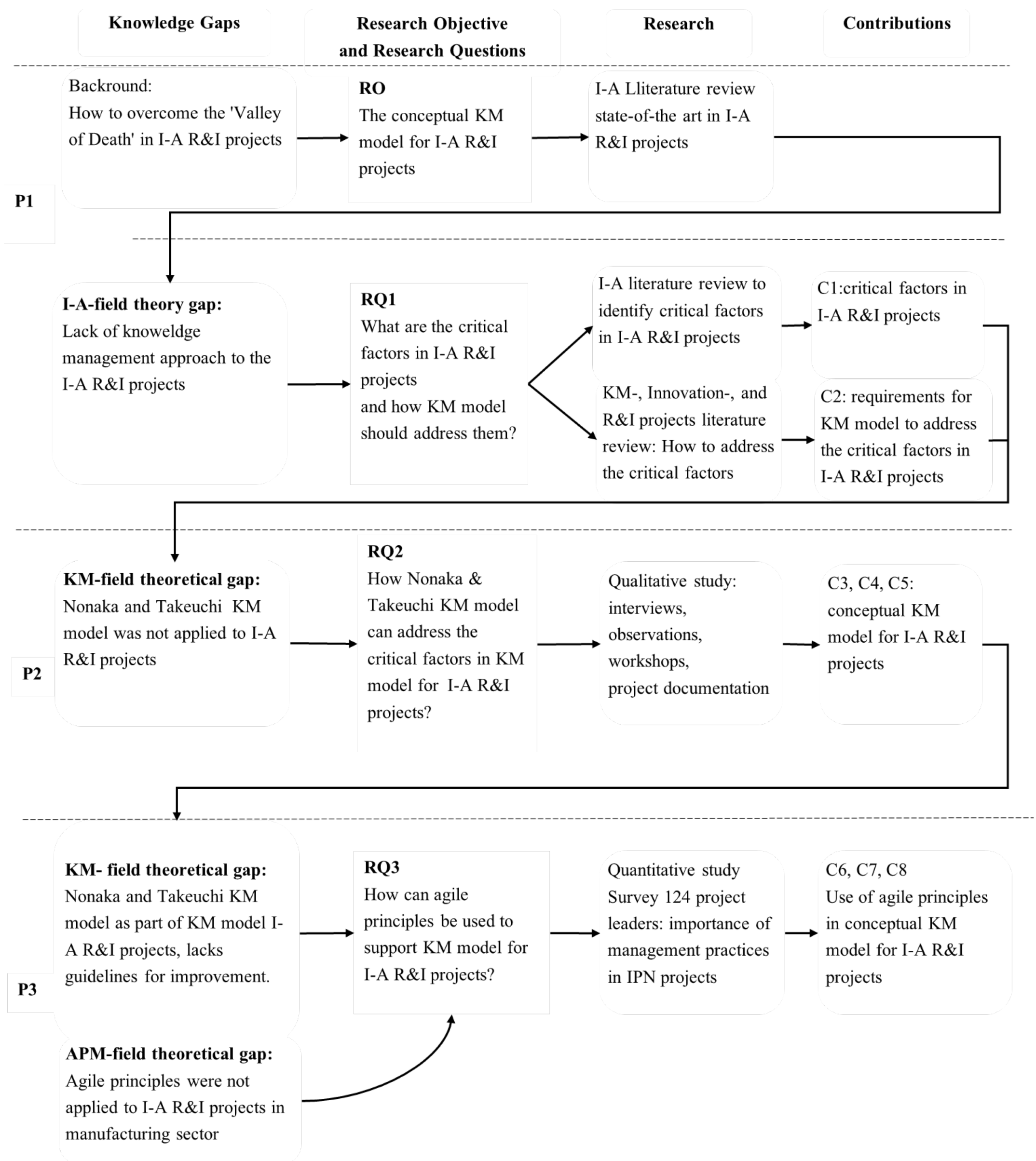

Fig 2. Knowledge gaps, research questions, methods, and contributions

2. THEORY

2.1 INDUSTRY-ACADEMIA COLLABORATION IN RESEARCH AND INNOVATION

In the I-A field, there is a need for concrete, practical management tools that can support project managers of industry and academia to organise innovation projects. The prior studies on I-A interaction concentrate largely on inputs in collaboration, such as motivations of partners and academic engagement and project outputs, such as the number of patents, licences, spin-offs, and articles published (Ankrah & AL-Tabbaa, 2015; Bazan, 2019; Bellini et al., 2019; Laine et al., 2015; Perkmann et al., 2021; Plewa, Quester, and Baaken 2005; Plewa and Quester 2007; Wohlin et al., 2011).

Several studies have focused on managing the collaboration between industry and academics from universities. However, they did not focus on the KM of projects. For instance, Jonsson et al. (2015) introduced a study on collaboration between Uppsala university and the industry. The study explored management tools that the university applied to create innovative interactions with the industry. However, even though this study contributed to the management of collaboration between industrial partners and academics, it did not investigate knowledge creation and learning processes in collaborative projects.

In another study, researchers at the Satakunta University of Applied Science created two models of open innovation processes between the university and industry. These models represent a two-step knowledge search for the industry. The first step identifies the company's technology needs. The next step is a more comprehensive knowledge search, where the researchers use their expertise and make prototypes to demonstrate technology opportunities for the company. The management models provide companies with better knowledge regarding the possible solutions for their challenges and support companies in making investment decisions (Laine, Leino, and Pulkkinen 2015). The management models of collaboration between industry and Satakunta University are created through the iteration between experts from the university and industry. However, industrial involvement is limited to feedback on the concepts created by the researchers. However, it is the researchers who work on the concept of new product or process, which is later presented for industrial evaluation. Thus, the concepts are not completely the result of joint industry-academia knowledge creation and the challenge to enhance combination of scientific and practical knowledge to innovation persists.

Plewa et al. (2013) examined the nature of university-industry linkages. The study presented a framework of success drivers along with collaboration. Some of the universal drivers are communication, understanding, trust, and the attitude of people involved. Although the human aspect is strongly emphasised, KM of the industry-academia research and innovation projects is not considered in the proposed framework.

Ivascu et al. (2016) proposed a business model for successful collaboration between universities and businesses. The model is a general framework that defined evaluation parameters, such as collaboration, knowledge sharing, culture, financial support, communication, and barriers. While some of the key success factors are knowledge-driven, there is no focus on facilitating knowledge processes and innovation.

Hermans and Castiaux (2017) explored knowledge transfers in university-industry collaborative R&D activities. They provided a new typology of university-industry collaborative research based on the alignment between the nature of a project and knowledge transfers. The study proved that these iterations strongly influenced collaborative R&D work. Even though the study concerned the knowledge transfer in R&D projects between industry and university, it encompassed knowledge flows within the project rather than through the project (Jiang & Li, 2009).

Overall, the literature review on I-A collaboration identifies the gap in the KM approach of I-A collaboration in R&I projects. The findings call for the first research question **(RQ1): What are the critical factors in I-A R&I projects, and how should the KM model address them?**
Main paper 1 presents the literature review that identifies the critical factors (C1) and how KM should address them (C2) in I-A R&I projects.

2.2 Nonaka and Takeuchi's knowledge management model

Fig 2 shows that the results from the first main paper, P1, initiated quantitative research. Interviews, observations, workshops and project documentation focused on critical factors (C1) and the requirements of KM in I-A R&I projects. The analysis of the obtained data showed much in common with the KM model of Nonaka and Takeuchi (Ikujiro Nonaka & Takeuchi, 1995). Their theoretical framework of organisational knowledge creation consists of two dimensions, epistemological and ontological, as shown in Fig 3. The epistemological dimension represents the conversion of knowledge between tacit (bodily, difficult to express by words) and explicit (codified, documented). Knowledge creation undergoes four conversion processes, including S(ocialisation), tacit to tacit, E(xternalisation), tacit to explicit, C(ombination), explicit to explicit, and I(nternalisation), explicit to tacit (Crossan, 1996). Transitions between tacit and explicit knowledge create a SECI loop that enriches the organisational knowledge base and generates a need for new knowledge, which triggers a new SECI cycle of knowledge creation. In this way, multiple SECI cycles create a knowledge spiral that reflects a continuous dynamic knowledge-creation process.

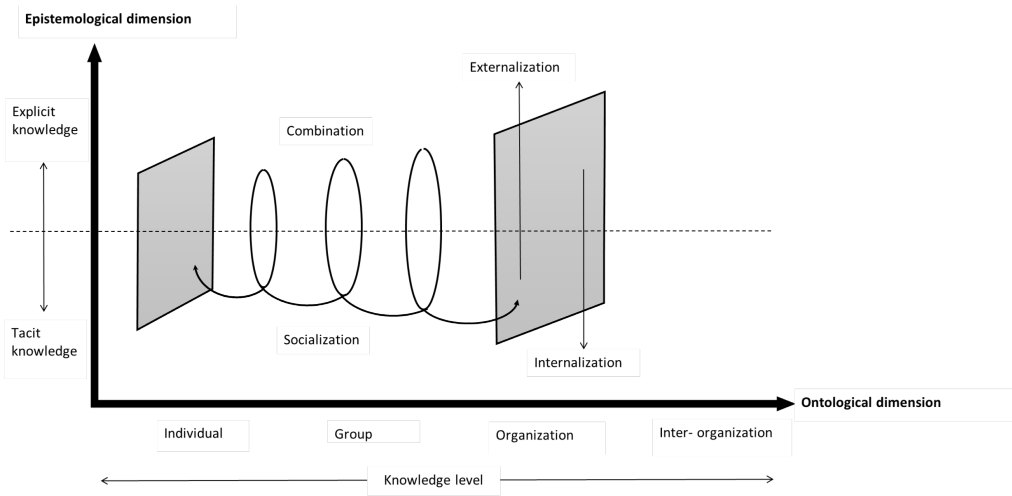

Fig 3. Nonaka and Takeuchi spiral of organisational knowledge creation (Ikujiro Nonaka & Takeuchi, 1995)

The ontological dimension is the transformation of knowledge by individuals into knowledge at group, organisational, and inter-organisational levels. These levels continuously interact with each other. The model introduces time as the third dimension. Fig 4 shows how time is introduced by t**he five-phase process of organisational knowledge creation.** The five phases are: sharing tacit knowledge, creating the concept, justifying the concept, building an archetype, and cross-levelling knowledge. The project team starts with *sharing tacit knowledge*. People share the knowledge they acquired through personal experiences in the specific knowledge fields. For instance, the technology integrator can provide insights into the feasibility of technology integration in factories. Based on the ability to share tacit knowledge, team members *create the concept* of a new product, process or service. The created concepts must be justified against criteria identified by knowledge goals and the needs of the society. *Justifying the concept* often involves experts outside of the project group. Once the concept is justified, it must be tested by an archetype. The last step, *cross-levelling of knowledge*, implies sharing knowledge derived from the project with the rest of the organisation. **This is how another spiral takes place at the ontological dimension** of the model. Knowledge developed by individuals results in group-knowledge at project-team level, which is further transformed into knowledge at organisational and inter-organisational levels.

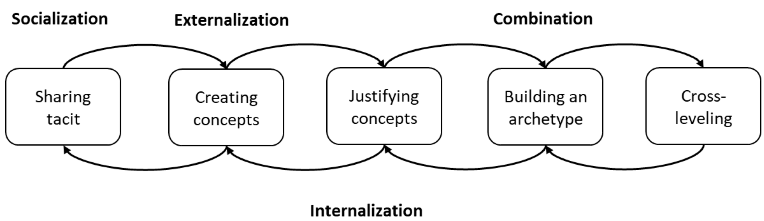

Fig 4. Five-phase model of organisational knowledge -creation process (adapted from Nonaka 1995b)

Interaction of the epistemological and ontological spirals over the time dimension represents the dynamic nature of the Nonaka and Takeuchi theory. Innovation emerges out of these spirals (Ikujiro Nonaka & Takeuchi, 1995).

The transformations of knowledge between tacit and explicit, individual and organisational, along these spirals address the critical factors related to facilitating knowledge creation in I-A R&I projects. This argues for the application of the Nonaka and Takeuchi model for I-A collaboration in R&I projects. However, the Nonaka and Takeuchi model is based on the study of business organisations, and it is not known if the model can be applied in the I-A context. It is also unclear how the Nonaka and Takeuchi model can address other critical factors in I-A R&I projects, those related to the formulation of collaborative strategies and objectives and learnings from project to project. The research gap triggers the second research question, **RQ2: How can the Nonaka & Takeuchi KM model address the identified critical factors for I-A R&I projects?**

Main paper 2 (P2) presents a qualitative study that seeks to answer RQ2. The study identifies the applicability of the Nonaka and Takeuchi model for I-A R&I projects. However, modifications to the model in the I-A context are required. The modifications constitute three additional contributions to the study: C3, C4, and C5. The first modification (C3) incorporates the five-step organisational knowledge-creation process of Nonaka and Takeuchi in three interdependent levels: strategic level of industry and academia separately, collaborative I-A strategic level, and I-A project level. The second modification (C4) implies the collaborative concepts that are specific for each level. Each concept consists of the management practices that address the critical factors. The third modification (C5) introduces continuous exploitation of new knowledge as an integrated part of the knowledge-creation process at each level. With these three modifications, the Nonaka and Takeuchi model is proposed as the conceptual KM model for I-A R&I projects.

2.3 AGILE PROJECT MANAGEMENT

The results of RQ2 identified the Nonaka and Takeuchi KM model as fundamental in the conceptual KM model for I-A R&I projects. Although Nonaka and Takeuchi's model is acknowledged as one of the most robust in the field of KM, it does not address how decision-making takes place when managing transformation between tacit and explicit forms of knowledge (Dalkir, 2017). Thus, this needs to be addressed in the proposed KM for I-A R&I projects, i.e., management practices that constitute the core of the collaborative concepts in the proposed KM model require some guidelines for improvement. Meanwhile, the management practices have much in common with the agile principles from agile project management. APM uses agile principles as guidelines to improve management practices. This raises the question whether agile principles can serve as guidelines to improve management practices in I-A R&I projects.

APM has proven effective for projects targeting innovation (Rigby et al., 2016a) (Rigby et al., 2016b). APM was inspired by the findings of Takeuchi and Nonaka published in the article 'The new new product development game' in 1986 (Takeuchi & Nonaka, 1986). The authors identified that the common reason for numerous successful innovations in Japanese companies was the new way of collaborating and organising product development. The inference was to 'stop running the relay race and take up rugby', implying that the traditional sequential project management approach cannot keep up with a constantly changing environment. Companies need to operate with self-organising, cross-functional teams that work with overlapping development phases. Later, in 2001, the findings from Takeuchi and Nonaka, together with other software development methodologies, became a foundation for the Agile Manifesto (Fowler & Highsmith, 2001). These methodologies were different, but they had a common ground: lessening and simplifying development rules for quicker adjustment to rapidly changing environments (Rigby et al., 2016b). The Agile Manifesto stated four basic agile values: *individuals and interactions over processes and tools*; *working software over comprehensive documentation*; *customer collaboration over contract negotiation*; *responding to change over following a plan* (*Agile Manifesto*, 2020). Twelve principles were then developed to support the agile values.

The principles fulfil the following criteria:

- deliveries of the working product in shorter time cycles;
- tight collaboration between developers and business people;
- empowering motivated individuals and a self-organising project team;
- encouraging face-to-face interaction between all stakeholders;
- reducing comprehensive documentation and quality defects (Beck et al., 2001).

There exist some studies of agile applications in I-A R&I projects. Sandberg et al. have conducted studies in software development in Sweden. The authors identified several best-practices related to the agile principles that were applied in successful R&I projects between industry and academia (A. Sandberg et al., 2011; A. B. Sandberg & Crnkovic, 2017). The findings identified the importance of the capability of projects to deal with the fast-paced changing business environment. This implied that projects should address only the research questions that allow adjustment to changing industrial goals. Organising meetings for engineers and researchers, and frequent deliverables to industry were also pointed out as innovation success factors related to the agile principles. The persistent practical deployment of the research results and visible presence of the researchers in the industry were emphasised by other studies on agile applications in I-A software development (Chookittikul et al., 2011; Grünbacher & Rabiser, 2013; Wohlin et al., 2011). However, these studies have been conducted in software development only. There is still a lack of evidence of the applicability of agile application in I-A innovation projects in, for example, manufacturing industries. Thus, the third research question is **(RQ3): How can agile principles be used to support the KM model for I-A R&I projects?**

A quantitative study has been conducted to answer RQ3. We surveyed 124 IPN project leaders (PL) (70 from the industry; 54 from academia) to evaluate the importance of the KM practices associated with the six agile principles across three project stages. The statistical analyses indicate the consistency of the agile principles throughout the project stages (C6). This means that agile principles are relevant for IPNs and can be used as guidelines for improving KM practices. Moreover, the study identifies the agile principles that are perceived as essential in different stages of a project (C7). It also identifies different perceptions of the importance of agile principles of the PL from industry and academia (C8). Thus, the findings contribute to close the knowledge gap concerning the use of agile principles to support the KM model for I-A R&I projects.

In summary, the study contributes to the three scientific fields. The use of the Nonaka and Takeuchi organisational knowledge-creation model in the I-A context contributes to the I-A and KM fields. The use of agile principles to support the proposed conceptual KM model for I-A R&I projects contributes to the APM, KM, and I-A fields.

3. METHODOLOGY

Table 2 presents an overview of the research methods used in the main papers (P1, P2, P3) and the supportive papers (Ps1, Ps2, Ps3) along with the paper-specific research questions, and their contributions. This thesis uses mixed-method research to achieve the research objective (Denzin, 2012). Literature study, qualitative, quantitative, and case study research are applied. Hence, the mixed-method research strategy employed in this study enabled more comprehensive and insightful findings than ones could be obtained by research method done. The use of the mixed-method research supports triangulation as an important way of strengthening the study's credibility (Patton, 2015; Yin, 2015).

Table 2. Research methods, main and supportive papers with the paper-specific research questions and contributions

Thesis development

Research Methods:	Literature review	Qualitative study		Case study to test the proposed KM model	Quantitative study
Data for research:	Industry-academia literature; Literature Knowledge management; Innovation; I-A R&I projects	- 15 individual semi-structured in-depth interviews, - 9 informal interviews ; - 7 observations of an ongoing project; - 2 workshops with total 14 PhDs and 2 senior researchers; - The IPN project documentation		Project documentation, research publications	Survey with 124 responders/project leaders: - 70 from industry
Main Papers:	P1	P2			P3
Supportive Papers:		Ps1	Ps2	Ps3	
Paper-specific RQ:	How to manage innovation processes in I-A R&I projects more efficiently and effectively?	- How to define long-term strategy? - How to define project objectives? - How to facilitate the projects to enable knowledge co-creation? - How to learn from project to project?	How to combine the DUI and the STI modes of innovation?	If the proposed KM model can support I-A R&I projects?	- Are the agile principles perceived as consistent throughout the IPN project? -How do PL perceive the importance of the agile principles in IPN projects? -How do PL from industry and academia perceive the importance of the agile principles in IPN projects?
Contributions	C1 C2	C3 C4 C5		Verfication of C3, C4, C5	Verification of C3, C4, C5 C6 C7 C8

The first main paper, P1, presents the literature review. The findings from the first paper, C1, and C2 trigger the next research step, which includes a qualitative study. The second main paper, P2, presents the qualitative research study and its findings C3, C4, and C5. These findings, in turn, creates a foundation for a (more) quantitative study. The third main paper, P3, presents the quantitative research study and the findings, which verify the results from the qualitative study and provide the contributions C6, C7, and C8.

The results in the supportive papers, Ps1, Ps2 and Ps3, helped in leveraging the research process. Ps1, the forerunner for main paper 2, identified several features of the conceptual KM model for the I-A R&I model (C4, C5), but did not consider the integration of the Nonaka and Takeuchi KM in the proposed model. The supporting paper, Ps2, explains in more detail how the proposed KM model for I-A R&I projects addresses the critical factors for the combination of different modes of innovation. Ps3 uses a case study to explore the practical application of the proposed KM model and thereby strengthen the basis for the contributions C3, C4, and C5.

3.1 LITERATURE REVIEW

P1 aims to design a practical approach for management of I-A R&I projects by focusing on knowledge transformation. This paper's research question is: How to manage innovation processes in I-A R&I projects more efficiently and effectively?

To answer this research question, a literature review was performed seeking evidence on (best-) practices in collaborative I-A R&I projects. Literature review was chosen as the research method because it serves to establish the current state-of-the-art in the field, while highlighting potential issues that require more research (Snyder, 2019).

The I-A literature review identified critical factors that industry and academia should address in I-A R&I projects (C1). To understand how to approach the critical factors from a knowledge perspective, the KM literature was reviewed. This supported the identification of KM requirements in the KM model for I-A collaboration in R&I projects (C2).

The literature review processes are explained explicitly in the following sub-sections.

3.1.1 Industry-academia (university-industry) literature review

Fig 2 shows how the literature review is integrated in the thesis research process. The primary purpose of this literature review was to provide the thesis with a comprehensive background for understanding current application of knowledge management in the field of 'university-industry collaboration' and highlighting the significance of new research. The literature review aimed to rationalize the thesis research objective to establish the conceptual KM model for I-A research and innovation projects.

Literature searches were undertaken using internet searching engine Google Scholar and university libraries. The keywords used to identify the relevant literature were: 'university-industry collaboration', 'university-industry research and innovation projects, 'university-industry open innovation', and 'university-industry knowledge management'.

Existing literature reviews on university-industry collaboration were obtained by using keywords 'literature review university-industry'. The results offered a good overview of the research that had been undertaken in this topic and helped to determine the relevance of the thesis research.

In addition, the names of researchers who had published a substantial amount of work in the field and were frequently cited by other authors were also used as keywords in the search. Some examples are, Perkmann M., Lundvall B., Carayannis E., and Plewa C.

In all the above searches, a maximum time frame of 10-15 years was placed on the dates of the works to be included. The most recent work was preferred, but this reduced the amount of available information. Seminal or influential works were the exception to this.

The UI literature review identified the scarcity of research on applying knowledge management to the context of university-industry collaboration. Some of the literature called for research on knowledge creation processes in U-I R&I projects to increase innovation from the projects, which led to the first research question **(RQ1) of the thesis: What are the critical factors in I-A R&I projects and how should the KM model address them?**

The same university-industry literature described above, has provided support in answering the first part of the RQ1: determination of the critical factors in university-industry collaboration. This constituted the first contribution of the thesis.

3.1.2 Knowledge management perspective: literature review

To answer the second part of the RQ1 on how the KM model should address the critical factors, the thesis turned to the literature that encompasses knowledge management, innovation, and research and innovation projects in Norway.

The review of the earlier studies on research and innovation projects showed that applied research dominated in the industrial sector, especially in Norway (B. Asheim et al., 2011a, 2011b; B. Asheim & Grillitsch, 2015; Maietta, 2015; Narula, 2004). This finding emphasized the importance of transformation between tacit and explicit knowledge and the combination of DUI and STI modes of innovation.

Since the thesis concerns innovation, innovation literature was also studied. The innovation literature review focused on how organizations supported knowledge creating processes to provide innovation. The PhD-course 'Innovative firm', taken by the author of the thesis at that time, inspired the choice of innovation literature. The literature consisted of seminal and influential articles that had hundreds or sometimes thousands of citations. The concept of 'absorptive capacity' by W.M. Cohen and D.A. Levinthal, 'open innovation' by H. Chesbrough, and 'innovative firm' by W. Lazonick were studied. The innovation literature shed light on structural and organizational conditions that enable organizational innovation and learning.

The thesis studied the work of I. Nonaka, G. von Krogh, and B.-A. Lundvall, and others influential scholars in the field of knowledge management. Knowledge management literature addresses both tacit and explicit forms of knowledge. It emphasizes the role of individual capabilities and interdependence between individual and organizational components as key factors in innovation processes.

The findings from the literature review formed the requirements for the KM model, which addresses the critical factors in I-A R&I projects. These requirements constituted the second contribution of the thesis (C2).

3.1.3 Analysis of the data obtained from the literature review

The findings from the literature review defined the critical factors in I-A R&I projects and the requirements of the KM model to address the critical factors.

The author of the thesis considered other KM models including von Krogh (Von Krogh & Roos, 1995; Roos & Von Krogh, 2016), Choo C. (Choo, 1996), Wiig K. (Wiig, 1994), and Boisot M. (Boisot, 1998). The analysis argues for the application of the Nonaka and Takeuchi model because this is the only model that meets all the requirements of the KM model for I-A collaboration in R&I projects. More precisely, the model focuses on the transformation between tacit knowledge and explicit knowledge as the bases for individual, group, organizational, and interorganizational innovation and learning.

Since the Nonaka and Takeuchi model is based on the study of businesses, it is not known if the model can be used for I-A R&I projects. It is also unclear how the Nonaka and Takeuchi model can help to define collaborative strategies, objectives, and how it can support learnings from project to project. This research gap generates the second research question, **RQ2: How can the Nonaka & Takeuchi KM model address the identified critical factors for I-A R&I projects?**

This question triggered the qualitative study.

3.2 QUALITATIVE STUDY

3.2.1 Data collection for the qualitative study

The results from the literature review identified the need for conducting a qualitative study on the processes of knowledge integration in I-A R&I projects. As people perform knowledge processes, the human dimension is always integrated into any project (Polanyi, 1958, 1966; Salter et al., 2014). Thus, individual experiences of those involved in the projects were essential for the study, meaning that interviewing was considered the most appropriate method of collecting data (Yin, 2015).

To strengthen the validity of the study, the principle of triangulation was applied both to the data sources (data triangulation) and data collection methods (methodological triangulation) (Denzin, 2012). The data sources included project leaders (PLs) from the industry and academia, and PhD students that were employed by the company and university.

The study at this stage focused on the critical factors (C1) addressed from the KM perspective (C2). Therefore, all the data collection methods concentrated on obtaining data that would answer four critical questions:

- How to define a strategy for long-term collaboration between industry and academia?
- How to define outcome objectives, so that they meet both industrial and academic demands?
- How to facilitate innovation projects to enable (more) knowledge co-creation?
- How to better integrate, build-on, store and retrieve knowledge in projects?

The data have been collected from the several sources, which are described in detail in the following.

- Fifteen individual semi-structured in-depth interviews.

The respondents were six academic PLs, six industrial PLs, two academic PhD candidates, and one PhD candidate employed by one of the companies. The **Interview guide for semi-structured interviews** is enclosed. The face-to-face interviews between the author of the thesis and each of the interviewees took place either at the company's location (office room) or at the university (classroom). Most of the interviews lasted for one hour, some of them nearly two hours, and one interview lasted for three hours.

The interviewees approved the analysed interview contents before further data conversion and use. Most of the interviews were recorded and transcribed. Recording, transcribing, and analysing first interviews, helped to build confidence in analytical interpretations of the data. When the author of the thesis felt sure that not sound-recording and transcribing would not decrease the quality of the research, she just took written notes during the rest of the interviews.

- Informal interviews and observations from the informal and formal project meetings

The author of the thesis asked permission to participate in some of the formal project meetings. The participant- observation in the project meetings assisted in understanding the real situation in the project (Yin, 2016). The conversations between the project participants were used as supporting data. The formal meetings lasted about an hour, however not all information in the meetings was relevant for the study. The number of meeting participants varied between two and five, and included the PLs, industrial and/or academic PhD and sometimes the other project stakeholders.

There were also informal meetings where the project was discussed, for example, during lunch or coffee breaks in the university. The informal meetings were usually between 10-30 minutes long.

During the formal or informal meetings, the author of the thesis was an observer, but when the opportunity presented itself, she asked the meeting participants a few questions. The questions fit naturally into the ongoing conversations and addressed the critical factors identified by the literature study (C1).
Notes were taken from seven observations of an ongoing project, including formal and informal I-A R&I project meetings. The attachment, **Observation formal project meeting**, shows the notes from the observation of the formal project meeting. Nine short interviews during formal and informal I-A R&I project meetings were conducted and documented as a part of this study. The attachment **Interview informal meeting**, documents one of the interviews.

- A workshop 'Addressing the critical factors in I-A R&I projects' with 14 PhD candidates and two senior researchers

Working in the university gave the author of the thesis the idea of engaging academics from the university in the study. Their experience from the collaborative university-academia projects had the potential to provide valuable information for the study. A workshop with 14 PhD candidates and two senior researchers was organized. The workshop consisted of three parts.

Part 1 'Presentation' (30 minutes): The author of the thesis presented the background of the thesis and the challenges for industry-academia collaboration.

Part 2 ‘Individual part’ (15 minutes): The researchers filled out individual forms about their experience in working in industry-academia research and innovation projects. This was done to ensure the relevance of their contribution to the study.

Part 3 ‘Group work’ (45 minutes): Discussion of the four critical factors in I-A R&I projects. The factors constituted the four questions for discussion.

For the discussion, the participants were divided into two groups with seven PhDs and one senior researcher in each. Each group had a facilitator that could explain the questions or support the discussions if needed. The author of the thesis was a facilitator for one of the groups, one of her PhD-supervisors was facilitator for the other group.

The reflection on the workshop is that PhD students found it difficult to answer the question about I-A collaborative strategy, but the rest of the questions generated a productive discussion. Documented **Workshop ‘Addressing the critical factors in I-A R&I projects’** is attached. It consists of the program and the questions for the discussion.

- Project documentation from the IPN project

The project publications and the reports provided additional data on how to address the critical factors (C1) from a knowledge management perspective (C2). A list of

Research articles from the Optimar-NTNU IPN project is attached. The majority of the project report is confidential; however, the company gave permission for this thesis to use the part of the final report that is about knowledge building, collaboration and utilization of the research results in industry and university. The attachment, **Excerpts from a qualitative summary and assessment of the IPN project Optimar-NTNU**, is enclosed.

3.2.2 Analysis of the data obtained from the qualitative study

Fig 5 shows the qualitative study process:

- The process started with inputs from the literature study (contributions C1 and C2),
- the interviews, observations, workshops and project documentation, which concentrated on answers about critical factors (C1) from the knowledge perspective (C2).
- obtaining statements and insights, and
- category interpretations of the data

Following Yin (2015), the analysis of the qualitative data followed a general, five-phased cycle : (1) *Compiling*, (2) *Disassembling*, (3) *Reassembling*, (4) *Interpreting*, and (5) *Concluding*. The first phase, *Compiling* data into a formal database, was done to organise the obtained data. The second phase, *Disassembling*, consisted of organising the data into the database and assigning some labels to the fragments of the data. *Disassembling* was repeated many times as a trial-and-fail process to refine the labels. This phase was followed by the *Reassembling* procedure; that is, the rearrangement and recombination of the data into different groupings and sequences. The fourth phase, *Interpreting*, was to interpret the reassembled data and create a new narrative. The fifth phase, *Concluding,* called for a conclusion from the qualitative research. The conclusion was the proposed KM model for I-A collaboration in R&I projects with contributions C3, C4 and C5. The model is presented in the second main paper, P2.

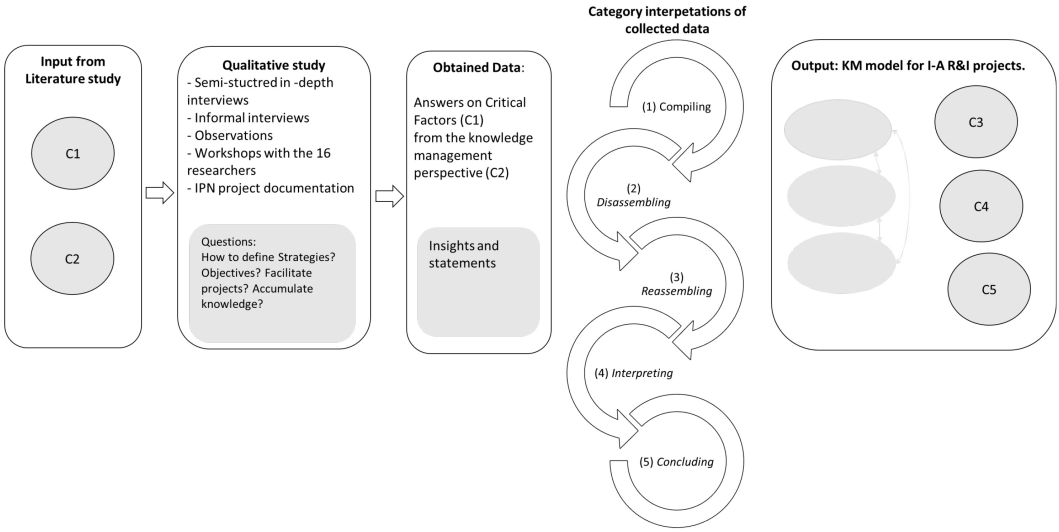

Fig 5. Qualitative study process

Table 3, Table 4, and Table 5 show the interpretations of the statements and insights from industrial (Ind. PL) and academic project leaders (Ac.PL), as well as from academic PhDs (Ac.PhD) and industrial PhDs (Ind.PhD).
Each of three tables corresponds to the collaborative level in accordance with contribution 3 (C3). The data has been categorized into the knowledge management practices that constitute the collaborative concepts (C4) and the practices related to knowledge exploitation (C5).

Table 3. Strategic industry and academia organizational levels: categorization of qualitative data

Statements and insights	Position	C 4 Knowledge management practices	C5 Knowledge exploiting practices
'The research-oriented culture in the company fosters the employees who have desire and ambitions to take PhD. It is important to facilitate their work and give them tasks that company needs to investigate. The industrial PhD –arrangement secures keeping the graduated PhD in the company for following 3-4 years.'	Ind.PL	Organisational resources for knowledge sharing, innovation, and learning	Facilitate the organisation to collaborate in research and innovation
'Academia should not run for money but run for competence building.'	Ac.PL		
'The role of the project leader is to disseminate knowledge'.	Ind.PL		
'They who generate idea(s) must have time to finish thinking it through and finish writing'.	Ac.PL	Accumulation of knowledge, learning from project to project	
'The industrial PhD is the only person in the company who possesses knowledge gained from that project. If he/she leaves, such knowledge disappears.'	Ind.PhD		
'Check that all resources needed are available before the project starts.'	Ac. PhD		
Dedicating resources to follow industrial and academic PhD closely is one of the solutions that allows exploiting the collaboration with academia.	Ind.PL		

Table 4. Strategic I-A collaborative level: categorisation of qualitative data

Statements and insights	Position	C 4 Knowledge management practices	C5 Knowledge exploiting practices
'The project should be aligned with the national strategic requirements. The project should be aligned with the research areas that are significant for the country and the region.'	Ind.PL	Align visions and strategy with regional and national ecosystem	Facilitate building common knowledge platform with others
'Work only with certain carefully selected strategic universities and invest in innovation projects with them in areas that are of core competence for the company.'	Ind.PL	Find the partner with matching knowledge domains.	
'We must select industry partners based on expertise we want to build. It must match the industry's strategies.'	Ac.PL		
'If researchers are passionate about basic research, they work with bigger companies. Big companies understand that research takes time… The researchers with industrial background recognise the needs of smaller companies for applied research.'	Ac.PL		

Table 5. I-A project level: categorization of qualitative data

Statements and insights	Position	C 4 Knowledge management practices	C5 Knowledge exploiting practices
'Management (industry) must take responsibility (for the project) at the start. It is a prerequisite.'	Ac.PL	Anchor project at management	Facilitate commitment to innovation process
'No project should start without the management taking a decision to go for it.'	Ind.PL		
'The company has to be involved in work with research application.'	Ind.PL	Involve industry to work with research application	
Working packages are defined in the research application.	Ac.PL		
'The strategy defines critical knowledge areas that company should build its competence on and alights the research objectives accordantly.'	Ind.PL	Align research objectives with organisation's strategic knowledge areas	
'It is important to show value in money.'	Ac.PL	Formulate research objectives targeting industrial value	
'To show the decision-makers that they can make a profit from the research.'	Ind.PL		
'The theoretical solution should provide serious value for the company.'	Ind.PL		
PhD research objectives should be adjusted to the company's actual needs.	Ind.PhD	Adjust PhD research objectives to company's needs and academic tools	
'The company adjusts PhD research objectives to the industry.'	Ind.PL		
'We do not focus very much on our perception, but what industry perceives as a challenge, and we find research questions according to that.'	Ac.PL		
'Before we define the research questions, we look at what kind of research tools we have available that can provide a fast value to the industry. At the same time, we know that research takes time, and the outcome is uncertain.'	Ac.PL		
'Clarification of partners' expectations from the research project is the prerequisite for the successful collaboration.'	Ind.PL	Clarify expectations from the project	
'Define in numbers value the project will deliver.'	Ac.PL		
Working packages are defined in the research application	Ac.PL		
'It is important to involve people from different company's departments. Arranging of interdisciplinary workshop brings lots of knowledge and different perspectives in the project.'	Ind.PL	Involve different knowledge contributors	Facilitate integration of innovation-

‘The companies with relevant knowledge expertise should be connected to the project from the beginning.’	Ac.PL	Involve external knowledge contributors	relevant knowledge
‘Involve technology integrator from the start.’	Ind.PL	Involve technology integrator from the start	Facilitate application of research results/ innovation
‘Integrator should be involved from the start of the project to ensure the feasibility of the industrialization.’	Ac.PL		
Project team should involve company’s suppliers and customers.	Ind.PhD	Involve company’s suppliers and customers	
‘Company’s customers and suppliers should be on-board before the project. They must verify the strong need for research.’	Ind.PL		
‘It is important that industry gives a little room for research, but it is industry that defines the directions for research.’	Ac.PL	Industry should navigate the project	Facilitate research and innovation process
‘Industry should follow the project closely to adjust the project’s tasks.’	Ind.PL		
‘As any other project, industry-academia project should have a plan with milestones.’	Ac.PL		
‘It is important to incorporate regular meetings.’	Ind.PL		
‘You get money, it's a special “puff” (enthusiasm). Industry has a positive attitude. One must use that energy. If you lose it, it “boils away” because industry has so many other things it must prioritize. Industry must see an immediate value from the project.’	Ac. PL	Create a ‘momentum’- important to deliver immediate value in the beginning	
‘The researcher must be able to understand industrial problems. He/she should speak industrial language.’	Ind.PL	Involve senior researcher	Facilitate trust
‘Send researchers to the industry. That helps to establish trust.’	Ac.PL		
‘PhD student has to understand industry.’	Ind.PhD	Integrate academic PhD in the company	
‘PhD student should spend lots of time in the industrial company.’	Ac.PL		
‘Often contact with academic PhD helped building good relationship with the company. It was fundamental for knowledge exchange and co-creation.’	Ac.PL		
‘PhD student should be humble. He/she should ask for help so that operators would feel important.’	Ind.PhD	Involve operators	
‘People talk as they are from different planets. It creates problems.’	Ac.PL	Apply industrial language	Facilitate communi-cation. Provide Mutual under-standing
‘Common language breaks down barriers in collaboration.’	Ind.PL		
‘Do not use academic terminology…Be a bit humble, more flexible.’	Ac.PL		
‘Prototypes help everyone, independent on the professional field, affiliation (university or company). Prototypes create an arena for discussions, common visions, and new ideas.’	Ac.PL	Use physical and virtual knowledge	

‘Use visual tools such as virtual prototyping and sketches. It is important from the very beginning. It supports common understanding. It helps to catch all aspects of the problem.’	Ac.PL	communi-cation tools	
‘We have learnt what we get and what we do not get from projects with academia. We know what we have to contribute with.’	Ind.PL	Learn how to work together	Learning to collaborate in innovation
‘If the company has experience with the research projects, it understands that research is demanding. The company understands that it cannot always get immediate results.’	Ac.PL		

The analytic process did not follow a linear sequence but had many iterations between the phases. The iterations resulted in the supportive papers Ps1 and Ps2. The former presents a conceptual KM model for I-A R&I projects with two of the three contributions (C4, C5); however, it does not integrate the Nonaka and Takeuchi KM model. The findings from a qualitative study were also used in the second supportive paper. Ps2 focuses on how the proposed KM model for I-A R&I projects addresses a combination of two modes of innovation through transformations between tacit and explicit knowledge.

3.2.3 Assessment of the category interpretations of the obtained data

Assessment 1. Individual discussions with the participants of the I-A R&I projects

Maxwell's (2013) recommendations were used to lessen the misinterpretation of the analysis of the qualitative data. The analysis of the data collected was presented to the six participants of the I-A R&I projects. Five of them had working experience in the industry and academia (three of them had a professor position, two had a PhD). The sixth person worked in the industry. Individual discussions with each participant lasted for about one hour.

The participants found the category interpretations for the qualitative data satisfactory.

Assessment 2. Workshop with the IPN participants

After the conclusions on the study were drawn, they were subsequently checked in the workshop with the participants from one accomplished IPN. The PL from the university, the academic PhD candidate and the industrial PhD candidate participated in the workshop. Owing to organisational changes in the company, the latter PhD candidate had to take on the role of project manager of the I-A R&I project. The participants were asked to evaluate the collaborative concepts related to the three levels of the KM model. The degree of importance was set to low, middle, and high. The participants assessed the concepts individually. The diverse background of the participants supported the triangulation principle, thereby strengthening the robustness of the conclusion

from the qualitative study findings (Patton, 2015; Yin, 2016). The participants found the category interpretations for the qualitative data satisfactory.

Assessment 3. Case study

Supportive paper Ps3 presents the case study that tests the results from the qualitative study (Ridder, 2017). Ps3 elaborates on the performance of the proposed KM model during different project stages. The research methods used were workshops where the three researchers discussed the project, project reports, meeting protocols and articles that provided data for this study. The researchers elaborated on how the novel knowledge management model for industry-academia collaboration is applied to the pre-project, the project, and post-project. The excerpts from the final project report are enclosed in the thesis (**Excerpts from a qualitative summary and assessment of the IPN project Optimar-NTNU**). The three researchers, who conducted the study in the Ps3, were involved in a project with one industrial company. One researcher was the project leader from academia (university) during the pre-project and the project. This individual has managed more than 20 I-A projects over several years. The other researcher was writing her master thesis on the pre-project and was later used as an observer in the project (the author of this thesis). The third researcher was an industrial PhD student employed by the industrial company.

The case study shows that the proposed KM model for I-A R&I projects has a potential to be applied in practice. This supports the theoretical contributions C3, C4, and C5 (Ridder, 2017).

3.3 QUANTITATIVE STUDY

3.3.1 The research goal for the quantitative study

The core of the proposed conceptual KM model for industry-academia collaboration in research and innovation is the Nonaka and Takeuchi model, which has proven to be among the more robust models in the field of KM. However, it has shortcomings. The model focuses on the practices that support knowledge creation and learning processes, but it does not address the principles that help to refine these practices (Dalkir, 2017). Meanwhile, a closer analysis of the results from the qualitative research on IPN projects showed that the identified management practices have a lot in common with six of the agile principles.

Fig 6 illustrates how the researchers saw the commonality between the management practices associated with the six agile principles from the Agile project management field and the industry-academia management phaticities in each of the three collaborative levels in the proposed KM model for I-A collaboration in R&I projects.

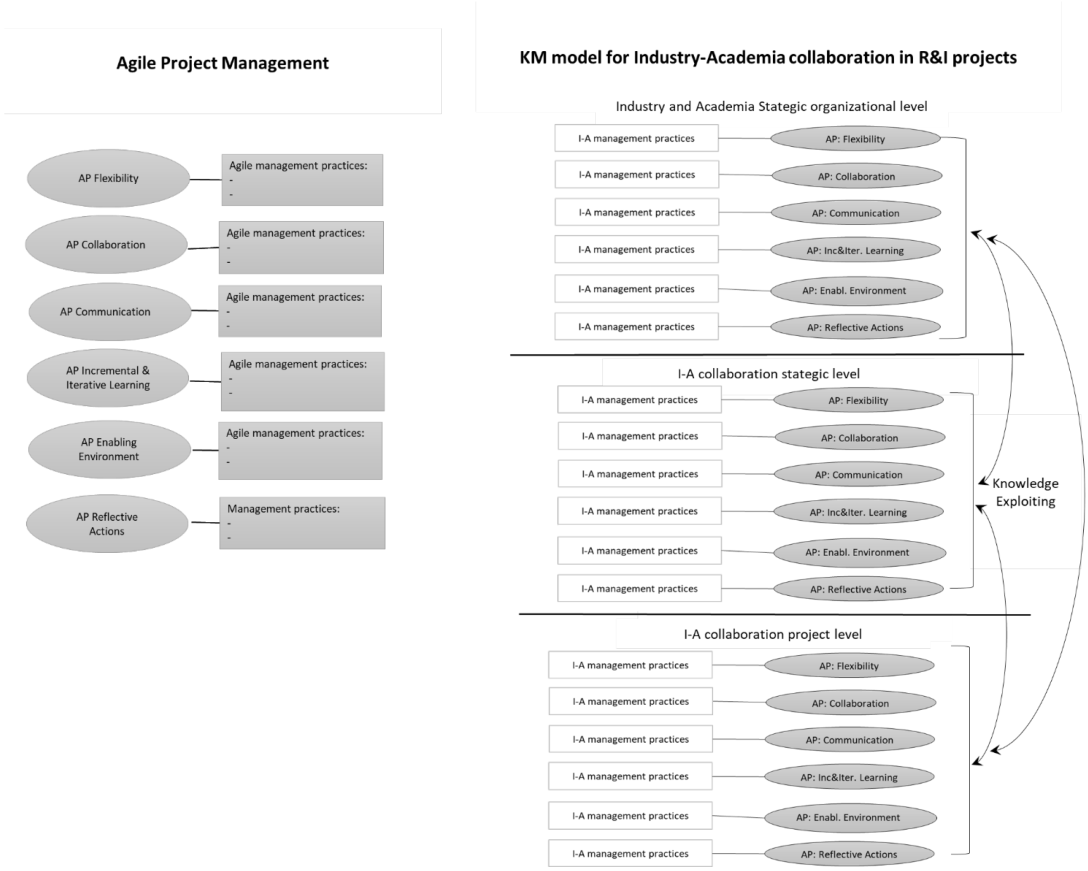

Fig 6. Commonality between the management practices associated with the six agile principles from the Agile project management and the industry-academia management phaticities in each of the three collaborative levels in the proposed KM model for I-A collaboration in R&I projects

In agile project management, the agile principles help project leaders to improve management practices and thereby optimise new product development continuously (Highsmith, 2009). Therefore, the thesis aimed to investigate if agile principles can do the same for IPN project leaders. Hence, the third research question (RQ3) for this study is, how can Agile principles be used to support KM model for I-A R&I projects?

The main paper three answers this question. It investigates the three paper specific research questions:

- Are the agile principles aligned with the management practices throughout the IPN project?

- How do project leaders perceive the importance of the agile principles in different stages of IPN projects?

- How do project leaders from industry and academia perceive the importance of agile principles in different stages of IPN projects?

The findings associated with answers to these questions constitute contributions C6, C7, and C8 of the thesis.

3.3.2 Data collection and survey development

The quantitative study aimed to generalise the answers from the large sample of the respondents. Therefore, survey research was considered as the most suitable approach (Nardi, 2018). The goal was to collect around 100-120 answers suitable for the research goal and sufficient for analysis by software for statistical analysis (SPSS) (Publishing, 2002; Julie Pallant, 2020).

To make the survey more comprehensible, the three levels of the proposed conceptual KM model for I-A R&I were adjusted to the three stages of IPNs, as shown in Fig 7. The adjustment aimed to approximate practical model applications so that the respondents could relate to the survey's statements and avoid misinterpretations.

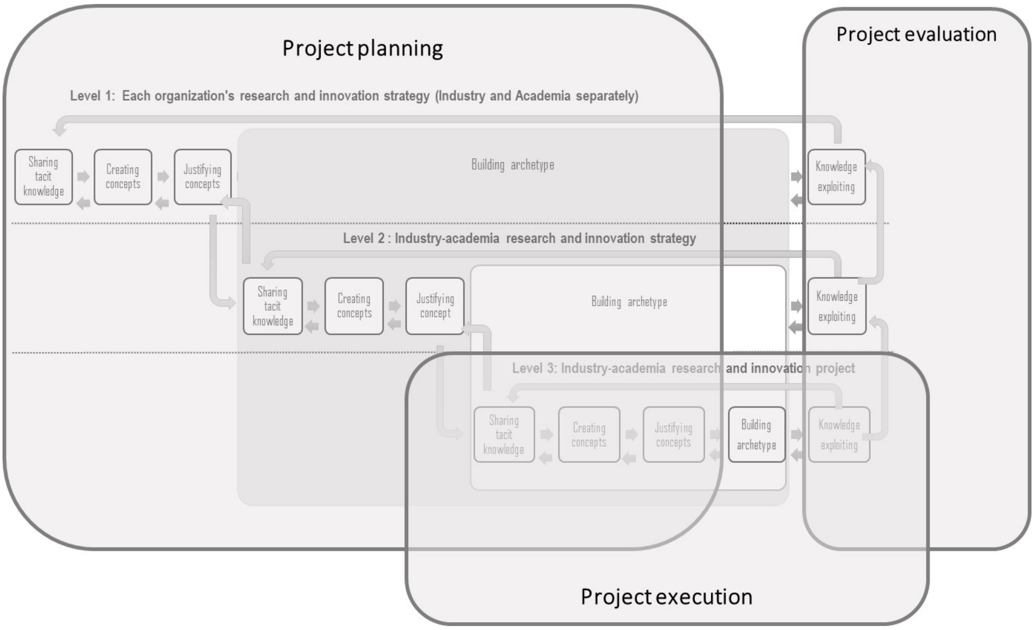

Fig 7. Adjustments of the three levels of the proposed conceptual KM model for I-A R&I projects to the three stages of IPNs, including planning, execution, and evaluation

Fig 8 shows how the three levels of KM model were adjusted to the three project levels with the management practices associated with the six agile principles.

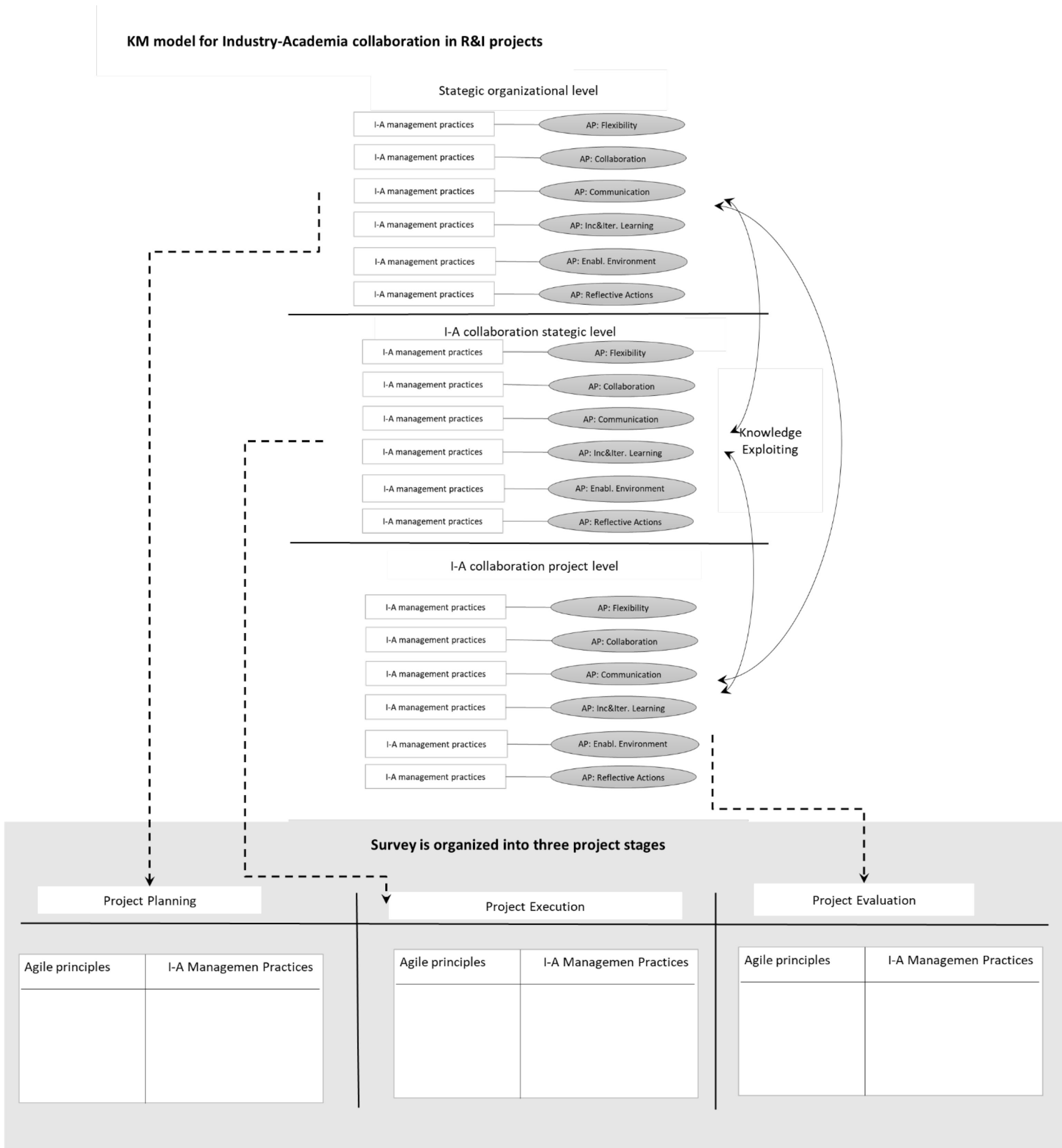

Fig 8. Organizing the survey into three project stages with management practices associated with the agile principles

Survey Quantitative study IPN projects with the management practices associated with the agile principles in the three IPN project stages is attached to the thesis.
Paper 3 presents the quantitative study on how PLs perceive the importance of the management practices associated with the agile principles in IPN projects. The perceived importance of the management practices was assessed on a Likert scale from one to five, where 'one' was not important and 'five' was very important. Before sending the survey to the respondents, it was piloted on the three PLs with work experience form both industry and academia. They confirmed that a five-point Likert scale was suitable (Dawes, 2008; Joshi et al., 2015). The pilot also confirmed that it was reasonable to adjust the three levels of the model to the three project stages in the survey.

Additional constructive feedback from the participants in the pilot helped in improving the survey in several aspects (Nardi, 2018). For instance, one of the comments was whether the PL should base the answers on their general experiences with IPNs or a specific project. The pilot indicated that it was better for the respondents to refer to the general IPN experience rather than to that of a specific project, since it was considered beneficial for the study to utilise a broad as possible range of project experience. The respondents were PLs for IPN projects, chosen based on the following conditions:

- The company operates within the manufacturing industry.
- The project was conducted during the period 2011-2019.

We used Google forms (*Google forms*, n.d.) to create a survey. Before sending out the survey link, respondents were contacted via a phone call to explain the survey and its purpose. The intention was to motivate PL to participate in the study and thereby increase the response rate.

The survey was sent to 189 selected PL identified from the RCN database (Research Council of Norway, 2020) and the PLs who work in the engineering department at the university. The survey was not notified to the Data Protection Services since the questionnaire did not contain information that could identify individuals directly or indirectly. Moreover, no identifying information about the respondents, such as their IP address or email address was collected (Data Protection Services (Norsk Senter for Forskningsdata), 2020). A reminder was sent once to all the respondents. Two weeks after sending out the survey, 124 responses were received.

3.3.3 Analysis of the data obtained from the quantitative study

The statistical software SPSS is used to analyse the data. A factor analysis (FA) indicates adequate correlation between the management practices and corresponding agile principles. The so-called Cronbach`s alpha (CA) shows the consistency of the entire survey and thus confirms its reliability (J Pallant, 2016). We test the validity of the correlations between the practices and the agile principles by evaluating the average variance extracted (AVE). The results confirm the validity of the correlations. Furthermore, the analyses show the existence of discriminant validity that confirms consistency between the project stages.

To find out how the PLs will use the agile principles in the IPN, we apply the FA to identify correlation coefficients between the agile principles in three project stages.

Next, we apply a one-way analysis of variance (T-test) to answer the third question posed in P3. The T-test identifies if there is a significant difference in assessing the importance of the agile principles between the PLs from the industry and those from academia.

3.4 VALIDITY

To assess the rigour of the theoretical contributions, the following acknowledged types of validity were considered: *internal validity, construct validity, and external validity* (Trochim & Donnelly, 2001). Though it is challenging to fully satisfy them all, this section discusses strategies for fulfilling them.

3.4.1 Internal validity

Internal validity concerns whether the results follow from the data (Trochim & Donnelly, 2001). Following Joseph Maxwell, several strategies were applied to combat the threats to internal validity (Maxwell, 2013). *Intensive long-term (field) involvement* implies *a complete and in-depth understanding of field situations, including the opportunity to make repeated observations and interviews.* The fact that the author has been working on the thesis along with colleagues working in the IPN allowed her to immerse herself in the field of study. One colleague was the project leader on behalf of the university; the other was an industrial PhD candidate employed in the company that owned the project; the third was an academic PhD. In this connection, many discussions and project activities daily, in addition to observing formal project meetings, were witnessed.

The closeness to the objective of the study provides opportunities for *intervention,* which is the other strategy that supports the validity of the study*. Intervention is about the presence of the researcher and observing how participants react as a further way of corroborating field patterns* (Maxwell, 2013). Colleagues have been aware of the author's research, and therefore physical presence increased their awareness of the knowledge perspective when managing the project.

In this thesis, a *triangulation* strategy is applied to collect converging evidence from different sources (Maxwell, 2013). With regards to the qualitative study, the data have been collected through observations made of the project activities, interviews with the PL and PhDs from industry and academia, workshops with the researchers, and project documentation. Collecting data from different sources allowed to the research team to get a deeper understanding of the field and strengthened the results of the study.

The PLs, who were respondents both in qualitative and quantitative studies, represent the different data sources in terms of their diverse background and experience (Patton, 2015). First, working in the industry and/or academia can impact their views on collaboration in R&I (Perkmann et al., 2021). Second, the size of the companies from where they have gained their experience, impacts their opinions. Innovation and KM are usually lacking in small-medium size enterprises (SMEs) (Bruneel et al., 2010; Brunswicker & van de Vrande, 2014; Wallin & Von Krogh, 2010). Therefore, respondents with experience in SMEs can have different opinions on managing collaborative R&I projects than respondents who have worked in larger companies.

Also, there is a difference between companies that have their own research and development department and the ones that do not have (Kazadi et al., 2016; Salter et al., 2014).This is related to the companies' capacity to establish the systems that manage knowledge and innovation (Wallin & Von Krogh, 2010). This, in turn, can affect the PLs perception of KM practices in the I-A R&I projects (Perkmann et al., 2021).

Moreover, previous experience in the I-A collaboration influenced the PL's attitudes in managing knowledge and innovation in the I-A R&I projects. The interviews showed that some companies with long working experience with research institutions have recognised that collaboration with academia requires a different approach than working with other business organisations. Therefore, they have developed collaborative routines for working with academia. It is the same with academia as the researchers who had more experience collaborating with the industry had developed methods to approach the I-A R&I projects.

Understanding KM in collaborative projects also depends on whether the PLs have mixed experience from both industry and academia, or only they have experience only from one of them (Perkmann et al., 2021).

3.4.2 Construct validity and reliability

Construct validity indicates how rigorously the study was organised to achieve the thesis's research objective (Trochim and Donnelly, 2001). Applying mixed methods research is the main approach to support the construct validity of the study. In this method, the triangulation principle is used to verify the findings of the study (Denzin, 2012; Patton, 2015). Verifications of the findings of the qualitative study are first done in workshops and using a case study. Then, the data obtained from the qualitative study—that is, the management practices—become the foundation for the survey in the quantitative study. The quantitative research tests the validity of the quantitative and qualitative studies by answering the research question RQ1 in the paper; that is, whether 'the agile principles are perceived to be consistent throughout the IPN'. The factor loadings, the reliability test CA, the validity test AVE, and the existence of discriminant validity indicate that management practices correspond well to the agile principles in the three project stages. The results verify the scientific rigour of the survey as a research instrument for collecting data, which ensures the validity and reliability of the research results (Pallant, 2020). The consistency of management practices in the survey verifies the findings from the qualitative study.

The verifications of the findings during the research process ensure the probability that other researchers will arrive at the same insights if they conduct the study using the same steps. This fact strengthened the reliability of the study (Gibbert et al., 2008). The results of the CA-test reinforced the reliability of the thesis as well. Furthermore, the methodology triangulation supports additionally the construct validity of the study (Patton, 2015). The triangulation method is applied to develop the conceptual KM model for I-A R&I projects by applying two strategies. The first strategy is to accumulate evidence from different sources to converge on a new construct. The second strategy is using the well-established theories to explore if they can support the achievement of the RO. The thesis followed the first strategy using the literature review and the qualitative study and arrived first at a more general, less well-specified concept of the KM for I-A R&I projects. This general model is described in the first supportive paper, Ps1. Simultaneously, the findings from the literature review and the qualitative study indicate that the well-established KM theory of Nonaka and Takeuchi can be used to achieve the RO. The Nonaka and Takeuchi KM model has the qualities that were defined by the literature review and the qualitative study. Merging the results from the two strategies resulted in the proposed conceptual KM model for I-A R&I projects.

3.4.3 External validity

External validity pertains to whether the generality of the results can be justified (Gibbert et al., 2008). This study is limited to the R&I projects in the manufacturing industry in Norway. The geographical constraint was necessary as each setting is unique to each particular industry and research institution; thus, the study requires a systematic evidence-based approach (Galan-Muros & Davey, 2019). In addition, both geographical and technological proximity are keys for open innovation (W. Vanhaverbeke et al., 2014). However, research on other types of industries in other countries may provide different outcomes. Nevertheless, the challenges for I-A collaboration in R&I projects are common within different industries worldwide (Bellini et al., 2019; Perkmann et al., 2013; Perkmann et al., 2021; W. Vanhaverbeke et al., 2014; Wohlin et al., 2011).Therefore, the results can be of interest to all involved in this kind of private-public partnerships projects, including the industry, academia, and policy-makers (Carayannis & Campbell, 2012; Martinez-Conesa et al., 2017). The limitations of the study are further discussed in Section 4.4.

4. DISCUSSION

4.1 ANSWERING RQ1—CONTRIBUTION 1 AND 2

RQ1: What are the critical factors in I-A R&I projects, and how should the KM model address them?

Main Paper 1 presents the results of the I-A literature review that provides the first contribution (C1) to the study; that is, the critical factors that may help overcome the challenges in I-A R&I projects. Further, the study of KM and open innovation literature provides the requirements of KM to address the critical factors. This constitutes the second contribution (C2).

Table 6 summarizes the critical factors (C1) and the requirements to KM model addressing the critical factors (C2).

Table 6. Critical factors (C1) and the requirements to KM model to address the critical factors (C2)

Critical factors (C1)	Requirements to knowledge management model to address the critical factors (C2)
How to define a long-term strategy for I-A collaboration in research and innovation projects?	- Long-term knowledge-building perspective in defining strategies - Consideration of the resources, skills, and efforts of the people in the organizational learning process
How to define I-A R&I project objectives such that they meet academic and industrial requirements while facilitating innovation?	- Define the projects objectives and the results in terms of new knowledge acquired and the degree of implementation in industry
How to facilitate I-A R&I project to enable knowledge creation and innovation?	- Support transformation between tacit and explicit knowledge - Support interaction between individual and collective learning - Support combination of DUI and STI modes of innovation
How to accelerate the rate of learning from each I-A R&I project?	- Dissemination of knowledge and continuous learning from the project - Integration of knowledge across organizational levels and between organizations

The literature review shows that the industry turns to academia for help sporadically when it faces a problem. (Plewa et al., 2005; Plewa & Quester, 2007; Bruneel et al., 2010). The lack of systematic knowledge building from the collaborative efforts does not contribute to the sustainable development of a knowledge-based society (Leydesdorff, 2018). This highlights the first critical factor to be addressed by KM:

How to define a long-term strategy for I-A collaboration in R&I projects?

Since organisational knowledge consists of the knowledge of individuals, it is important that industry and academia dedicate resources for collaboration in innovation (Ikujiro Nonaka & Takeuchi, 1995). Thoughtful allocation of the resources, skills, and efforts is imperative for systematic knowledge

building and the ability to innovate (Cohen & Levinthal, 1990; Kapoor et al., 2016; B. Lundvall, 2007;(Cohen & Levinthal, 1990) Schulze et al., 2014).
The literature review highlights that the industry and academia have different agendas when collaborating on innovation. The research publications, licences, and number of patents are the key performance indicators for academia, while the industry needs to be profitable (Perkmann et al., 2021; Wohlin et al., 2011). Moreover, innovation is uncertain, and it is difficult to be sure about the results of the innovation processes (Kanter, 2000). It is thus challenging to define the I-A project objectives. Both industrial and academic benefits should be derived from the project. Therefore, the second critical factor to be addressed by KM of I-A R&I projects is:

How to define project objectives such that they meet the academic and industrial requirements, while facilitating innovation?

It is proven that structural conditions, formal and informal incentive systems, and norms for internal and external collaboration are crucial for learning and innovation processes (Hargadon & Sutton, 1997). Different forms of collaboration between academia and industry require different support structures and motivation mechanisms (Perkmann et al., 2013). Therefore, we take into consideration the particularities of the studied context.

The study deals with innovation projects in the industrial sector restricted to mechanical engineering and industrial design. Incremental type innovation is typically of research interest in this type of projects, rather than radical innovation that is more common target in basic research (Narula, 2004; B. Asheim & Grillitsch, 2015). Characteristically, companies innovate rapidly while doing-using-interacting with their customers and suppliers, which refers to DOU-innovation mode. This innovation is based on tacit knowledge gained from working with products, processes, suppliers, and customers. Nevertheless, to stay competitive in the global market, the local industry needs to integrate the explicit scientific knowledge of researchers anchored in the science and technology-based innovation (STI) mode (B. Asheim et al., 2011; Jensen et al., 2007; B. Å. Lundvall, 2007). The two types of innovation have their origin from different types of knowledge, tacit and explicit. Thus, facilitating interactions between tacit and explicit knowledge, and between DUI and STI modes of innovation, is critical to the success of IPNs.

The role of individual capabilities and interdependence between individual and organisational components are key factors in innovation processes, meaning that organisational practices should support individuals to become more effective innovators (Amabile, 1988; Kanter, 2000; Salter et al., 2014). Therefore, the transformation between the individual and organisational capabilities should be considered in managing the IPNs (Nonaka, 1994; Nonaka & Takeuchi, 1995b).

The other barriers to successful innovation in I-A collaboration are similar to those faced in large firms. Different divisions of a large company are like different 'thought worlds' where individuals organise their thinking and actions concerning innovation in their own way, or so-called 'interpretive schemes' (Dougherty, 1992). The same situation is relevant for academia and industry that think in distinctly different ways, which emphasises the importance of creating a common language in IPNs. This leads to the third critical factor that should be taking into consideration:

How to facilitate I-A R&I projects to enable knowledge creation and innovation?

The transformation between tacit and explicit knowledge, DUI and STI modes of innovation, interactions between individuals and organisations, and creation of common languages are the KM perspectives that should address this critical factor (Krogh et al., 2000; B.-Å. Lundvall, 2012).

When using external knowledge for internal innovation, organisations must absorb the new knowledge (Cohen & Levinthal, 1990; Kapoor et al., 2016). Increasing organisational absorptive capacity challenges KM to build organisational forms that promote learning from each project (Jensen et al., 2007; B. Lundvall, 2007; Wim Vanhaverbeke & Cloodt, 2014).Learning from project to project means not only storing the knowledge about previous projects, but also transforming, generalizing and making it accessible to others, and being able to retrieve it for new projects (Hargadon & Sutton, 1997; Walsh & Ungson, 1991). Therefore, the fourth critical factor to address in I-A R&I projects is:

How to accelerate the rate of learning from each I-A R&I project?

All the above requirements of KM, which address the set of critical factors, constitute the second contribution (C2). It can be summarised as follows:

- Knowledge perspective in defining strategies and objectives;
- The conversion between tacit and explicit knowledge;
- Interaction between individual and organisational knowledge;
- The combination of scientific (STI) and practical (DUI) modes of innovation;
- Dissemination of knowledge, continuous learning, and integration of knowledge across organisational levels and between organisations.

4.2 Answering RQ2—Contributions 3, 4, and 5

RQ2: How can the Nonaka & Takeuchi KM model address the identified critical factors for I-A R&I projects?

The qualitative study identified that the KM model of Nonaka and Takeuchi addresses the critical factors and meets the requirements of the KM model for I-A R&I projects. However, three modifications of the Nonaka and Takeuchi model are required to address the critical factors in the KM model for the I-A R&I projects. Main Paper 2 presents these findings. Whereas the supportive paper Ps2 clarifies how the model addresses the combination of two modes of innovation and the conversion between tacit and explicit knowledge.

Fig 9 shows the conceptual KM model for the I-A R&I projects with the Nonaka and Takeuchi KM model modified for the industry-academia research and innovation projects. The modifications constitute three contributions of the thesis: C3, C4, and C5 of the thesis, which will be elaborated in the following sub-sections.

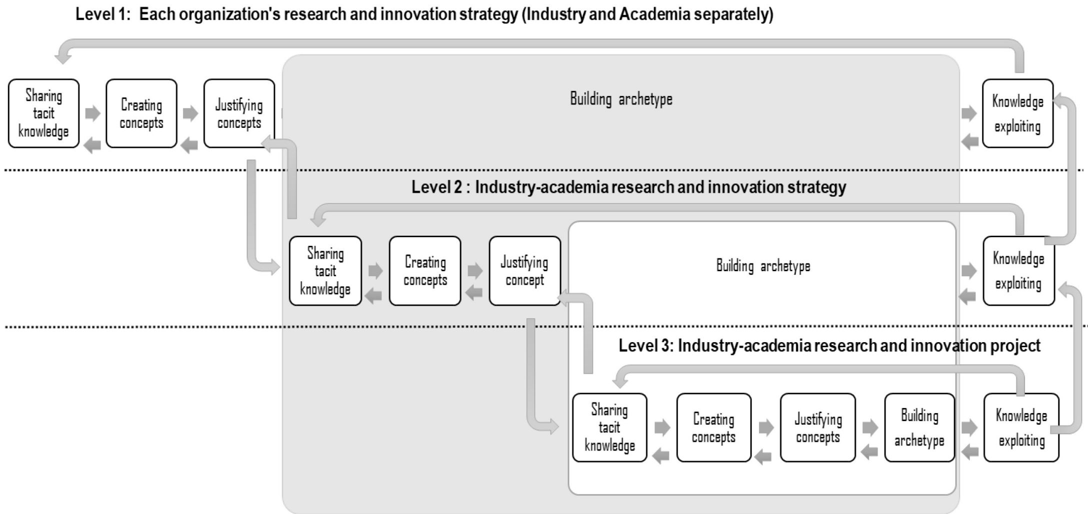

Fig 9. Conceptual knowledge management model for industry-academia collaboration in research and innovation projects (adapted from main Paper 2)

4.2.1 Contribution 3. Integration of the Nonaka and Takeuchi KM model in three interdependent levels

The first modification (C3) is the integration of Nonaka and Takeuchi's five-step organisational knowledge-creation process in three interdependent levels:

- Level 1: Each organisation's R&I strategy (separately industry and academia)
- Level 2: The I-A R&I strategy
- Level 3: The I-A R&I project

The knowledge-creation process in each level is built around the concept. Each concept consists of the management practices that address critical factors. The management practices define collaborative strategies and objectives as follows:

- At level 1, the industry and academia define the strategy for R&I development for their organisation. Their strategies should be aligned with regional and national strategic development. To benefit from collaboration, industry and academia should dedicate and allocate resources for learning and innovation in their organisations (Kapoor et al., 2016; Lazonick, 2015; H. Chesbrough & Bogers, 2014; Wim Vanhaverbeke & Cloodt, 2014).
- At level 2, the industry and academia define the long-term collaborative strategy and the actions to achieve it. Continuous building of new knowledge through enduring collaboration in innovation will increase industry's and academia's ability to innovate (Chesbrough & Bogers, 2014; B.-A. Lundvall, 2006; B. Lundvall, 2007).

- At level 3, each project is incorporated into I-A strategic development. Solving specific industrial and research challenges at project level brings the industry and academia closer to their strategic R&I goals.

The integration of the project level into the I-A collaborative level and integration of the latter into the top management level reflects the necessity of top management to support and prioritise the projects by allocating sufficient resources, even in competition with operational needs and daily business.

The interdependency between the three levels provides continuous improvement in the collaborative concepts at all levels of the KM model for I-A R&I. Fig 9 shows that each organisation's concept of collaboration in innovation (level 1) is verified at the I-A collaborative level (level 2). Here, the step 'building archetype' at level 1 triggers the knowledge-creation process at the I-A collaborative strategic level 2. Both concepts go through the test on project level: the knowledge-creation process at project level three evaluates the quality of the concepts from the levels above. Thus, the project serves as an archetype of level one and level two. For instance, a constant shortage of resources from the university and academia in the project would imply a revision of the collaborative concepts at all levels. Continuous improvement is essential in addressing the critical factors of defining strategies and objectives. New knowledge obtained from the project and its outside changes the R&I objectives and strategies. The industry and academia should reflect and adjust the collaborative goals accordingly at all levels. On the contrary, the relevance of the R&I objectives may be outdated, and the research results will not be realised.

In addition to the definition of the I-A strategies and objectives, the collaborative concepts at each level also focus on the facilitation of knowledge creation and learning. The concepts with the management practices addressing the critical factors in the I-A R&I projects constitute the second modification of the Nonaka and Takeuchi KM model (C4). Section 4.3 describes this contribution in more detail.

4.2.2 Contribution 4—The collaborative concepts

The second modification of the Nonaka and Takeuchi model for the studied context provides the fourth contribution of the thesis (C4): The collaborative concepts in the KM model for I-A R&I projects consist of the management practices that address the critical factors in these projects. The collaborative concepts define how to manage knowledge creation and learning processes at each level and between the proposed conceptual KM model levels.

Table 7 presents the collaborative concepts that collectively address the critical factors in the IPNs. The collaborative concepts consist of the management practices that help identify collaborative strategies and project objectives, as well as facilitate knowledge-creating and learning processes.

Table 7 Collaborative concepts at the three levels of the KM model for I-A R&I projects

Level	How to define collaborative goals	How to facilitate knowledge creation and learning
Organisation's strategic level	Instil knowledge vision and strategy with national and regional directions for innovation	Dedicate and allocate resources for collaboration: • PhD programmes • Industrial management and senior researchers support PhDs • Interdisciplinary collaboration in the organisation
I-A collaborative strategic level	Building knowledge platform: I-A long-term collaborative strategy	• Clarification of partners' expectations • Strategic I-A project group: members are involved in many I-A projects • Absorptive capacity of those involved: industrial and academic background
I-A project level	Project objectives are aligned with I-A collaborative strategy	• Clarification of partners' expectations • Anchoring the projects in industry top management • Industry should navigate the project • Active involvement of internal and external stakeholders • Common language: integrating researchers in industry, building prototypes • Create a momentum: keep enthusiasm from the project start

The collaborative concepts concern each of the five phases in the knowledge-creation process. All the phases across all the levels in the proposed KM model jointly address the critical factors. We elaborate on the phases in the following.

Sharing tacit knowledge includes sharing experiences to enable sharing mental models. This research reveals that the involvement of people with backgrounds from academia and industry, such as senior researchers and highly educated industrial employees, contributes to better understanding between industry and academia. Integrating academic PhD candidates in a company's operational environment generates common experience with the industry, making it easier to share tacit knowledge. The industry and academia knowledge strategies crystallise the multiplicity of shared mental models in one direction (Nonaka, 1994). The managerial initiative at the project level to create momentum by delivering value at the beginning of the project quickly generates a positive collaborative experience and accelerates sharing of tacit knowledge. For instance, researchers can use their methodological tools to solve a few minor industrial problems at the beginning of the project.

Concept creation emphasises the dedication of the resources for collaboration in R&I. In practice, partners should assign which knowledge contributors are required for the project and the adequate quantity of time they will use on the project. For instance, a project requires that one engineer uses 40% of their time, two days a week, to design the prototype and participate in prototype building. The mechanic and electrician each will use 20% of their time to work on the prototype. The same also concerns academia. The project manager, on behalf of the academia and the researchers from the required knowledge fields, for example, an expert in automation and a software developer, will assign the time to work on the project. Dedication of resources is crucial for project success. Otherwise, daily routines will take over, and the I-A research innovation project will be given less priority. *Concept creation* also implies initiatives that support 'shared language'. Avoiding academic terminology and the use of industrial language, sketches, drawings, and mock-ups promote mutual understanding. Many respondents emphasised the role of the strategic I-A project group that collaborates on many technological projects. They claimed that accumulating collaborative experience helps executing the project more effectively.

Clarification of expectations in strategies and objectives supports c*oncept justification.* The study shows that top management in the industry and academia are primarily responsible for incorporating justification criteria in organisational knowledge vision and strategy, which must be consistent with the national and regional plans in research and development. The collaborative I-A unit should establish a set of sub-criteria in the form of an I-A collaborative strategy for a long-term partnership, which is in line with the knowledge strategies of organisations. Consequently, the project objectives present the set of sub-criteria coinciding with the justification criteria at the above levels. The research questions should be defined in line with industrial needs and should be flexible owing to uncertainty in R&I projects. Involving stakeholders, people from different departments in companies, universities and/or research institutions, and end-users of future innovative solutions is vital for creating and justifying the concepts (Nonaka & Takeuchi, 1995a; Rigby et al., 2016b).

Building archetypes is a necessary part of creating a new process or new product. The study indicates that rapid prototyping and frequent interactions with users are a prerogative for success. Additionally, a prototype is a great communication tool for people from different backgrounds. The interviews and survey show that using prototypes frequently will improve communication between the industry and academia and increase the quality of the knowledge creation and learning processes.

The last phase in the KM model of Nonaka and Takeuchi is *cross-levelling of knowledge*; it refers to the dissemination of knowledge in the organisation through individuals (Ikujiro Nonaka & Takeuchi, 1995). The thesis indicates that in the I-A context, the emphasis in this step is *not only on knowledge dissimilation but also* on *knowledge exploiting*. Thus, it makes its own contribution to the science, as described in Section 4.3.1.

The identified management practices support the combination of the STI and DUI modes of innovation and the tacit-explicit knowledge conversion process. Supportive paper Ps2 elaborates the combination of the two modes in detail.

Table 8, adapted from Ps2, indicates how management practices fall into four modes of knowledge-creation processes: socialisation (S), externalisation (E), combination (C) and internalisation (I) that constitutes the SECI circle in the KM model of Nonaka and Takeuchi (Nonaka, 1994; Nonaka & Takeuchi, 1995a; Nonaka et al., 2000). Anchoring management practices in the SECI cycle explains how management practices can support knowledge creation and learning in IPNs.

Table 8 Management practices that support the combination of DUI and STI modes of innovation in the SECI knowledge-creation cycle (adapted from Ps2)

Conversion process	Management practices to combine DUI and STI
S	Incorporation of projects in the industrial environment Incorporation of students in the industrial environment Active engagement of operational users Absorptive capacity of those involved
E	Industry defines the project objectives in research applications Research objectives must address industrial need Research objectives must consider absorptive capacity of those involved Clarification and quantification of project results Commitment and quantification of resources
C	Integration of realistic data in the project Rapid, frequent prototype building
I	Gradual assimilation of knowledge in both organisations Refining of project and research objectives at the end of each SECI cycle Revising of knowledge management guidelines at the end of each SECI cycle

4.2.3 Contribution 5—Continuous *knowledge exploiting*

The second main paper (P2) and the first supportive paper (Ps1) describe the important role of *knowledge exploiting* in the proposed conceptual KM model for I-A R&I projects. The fifth contribution to the study is C5: Continuous *knowledge exploiting* improves the collaborative concepts and integrates dynamic into the KM model for I-A R&I projects.

Continuous *knowledge exploiting* addresses the critical factors in I-A R&I projects. First, it ensures learning from project to project. The P2 and Ps1 reveal that the industry and academia should not wait till the final research results but exploit new knowledge throughout the project. Regular communications, presentations, workshops, and the building of prototypes allow partners to create new knowledge and incrementally implement it in organisations during the project. In this connection, one CEO stated: 'The company has to be in dialogue (with academics) to get the knowledge. It does not need to be the final report or an article.'

Fig 9 shows that *knowledge exploiting* provides the dynamics of knowledge-creation processes within the levels and between the levels in the proposed KM model. First, we will consider the top-down dynamics between the levels. The industry and academia should integrate management practices related to *knowledge exploiting* in the organisations' strategies and the I-A collaborative strategy. Management practices should ensure the sufficiency and adequacy of resources for learning and innovation for a long-term collaboration in R&I. This is the task of top management. Some specific examples were given by the interviewees. For instance, utilising an industrial PhD programme is a beneficial way of exploiting knowledge in the industry. According to the contract, the industrial PhDs has to stay with the company for the next 3-4 years after project completion. This secures the accumulation and dissemination of knowledge from the projects across the company and further development and implementation of the project research results. For academics, the research achievements must be published, which requires that management gives additional time to the project work. When academic partners belong to a university, the university's management should provide enough time for the academics to integrate new knowledge into educational programmes and develop it further through other projects with the industry. This can be illustrated by a statement from one of the academic project managers: 'It (knowledge) must be externalised, you (researcher) need to connect with others and build it into teaching as well as into your next project'. Dissemination of knowledge also happens through students who participate in projects where the new knowledge is generated.

Furthermore, *knowledge exploiting* on the project level triggers continuous improvement of the collaborative concepts from the project level up to the strategic levels 1 and 2. New knowledge obtained during the project initiates modification of the collaborative strategies and project objectives. Modifications of the industrial and academic goals ensure that the project will stay relevant during its 3-4 years. According to the interviewed PLs, the relevance of the project goals ensures that the industry and academia provide sufficient resources to conduct the project and implement the research results in an industrial setting. Moreover, *knowledge exploiting* creates double-loop learning that optimises the organisations' knowledge strategies and the I-A collaborative knowledge platform (Cyert & March, 1963). This has great potential to amplify the innovation impact from each collaborative project and contributes to a knowledge-based society (Carayannis & Campbell, 2012).

The study emphasises users' involvement in knowledge creation and learning processes. The case study described in paper Ps3 demonstrates that *knowledge exploiting* by users is essential for the IPN success. Based on new knowledge, users can navigate innovation development, both within the project and at strategic organisational levels. This increases innovation the potential in the project and strengthens the innovation capability of the partners involved. The users can be, for instance, operators in the company, which will produce the developed technology or an external customer. Moreover, the study shows that when potential users actively contribute to the project, it provides them with a sense of ownership of the new knowledge created and the willingness to exploit it. The study also reveals that technology integrators, which can be a third party involved in the project, should participate in *knowledge exploiting*. Their contribution to knowledge-creation and learning processes ensures the feasibility of implementing the research results.

In this way, *knowledge exploiting* at each level and between the levels contributes to the continuous improvement of management practices that facilitate I-A collaboration. This allows obstacles for collaboration to be overcome and consciously supports conversion between tacit and explicit knowledge, and the combination of practical and scientific innovation modes. *Knowledge exploiting* during the project, rather than waiting until its end, makes the model dynamics, allowing the IPN to stay relevant to industrial and research needs, thus avoiding the 'valley of death'.

4.3 ANSWERING RQ3—CONTRIBUTIONS 6, 7, 8

RQ3: How can agile principles be used to support the KM model for I-A R&I projects?

Paper 3 describes the qualitative study of the use of agile principles in IPNs. The study provides three additional contributions to the thesis, which are described in the following sub-sections.

4.3.1 Contribution 6—Correlations between the agile principles and the management practices

The results identify the next contribution of the thesis, C6: Agile principles are consistent with management practices in the KM model for the I-A R&I projects. The consistency shows that the PL can rely on the categorisation of management practices concerning the agile principles in IPNs. Thus, PL can adapt the agile principles as guidelines for improving management practices.

Since the Nonaka and Takeuchi KM model is fundamental in the conceptual KM model for I-A R&I projects, the findings made herein contribute to the KM theory. Although Nonaka and Takeuchi's model is acknowledged as one of the most robust in the field of KM, it does not examine how decision-making takes place when managing transformation between tacit and explicit forms of knowledge (Dalkir, 2017).

C6 shows that decision-makers can use the agile principles to improve management practices to support tacit-explicit knowledge conversion in IPNs. This can solve the challenges of the Nonaka and Takeuchi KM model in the context of I-A collaboration in R&I projects. The analysis of agile principles consistency draws attention to the slightly low factor loadings for the 'Communication' principle in the execution stage. The reliability (CA) and validity (AVE) tests, and discriminant validity coefficients compensate for the results on the 'Communication' principle. However, it is important to understand PLs' perception of the 'Communication' principle. This is of particular interest since proper communication is vital in collaborative knowledge creation (Krogh et al., 2000; Nonaka et al., 2006).

Innovation combines knowledge embodied in different fields of expertise. It is well-documented that different organisations, and departments within an organisation have challenges with communication. At the individual level, experts from different knowledge fields frequently have challenges interacting and understanding each other (Amabile et al., 2005; Fleming et al., 2007; Galan-Muros & Davey, 2017; Milliken et al., 2003). As a countermeasure, APM focuses on daily face-to-face interactions of business people and developers throughout the project (Highsmith, 2004; *Principles behind the Agile Manifesto*, 2001).

However, an IPN project does not involve such frequent communication. An IPN is typically 'plan-driven' and works towards intermediate and long-term project goals. The IPNs rely on structured project plans with formal objectives, activities, and milestones throughout the project period. Since the project team has scheduled meetings (say, every 14th day), communication during the project tends to be in written reports with relatively few via face-to-face discussions. This might explain why many PLs with experience from structured IPNs perceive the 'Communication' principle, which is based on face-to-face interactions, to be less important than other principles. However, according to KM fundamentals, organisational learning relies on personal knowledge (Chesbrough & Bogers, 2014; Nonaka et al., 2006). Therefore, industry and academia should direct their attention to the application of the 'Communication' principle.

4.3.2 Contribution 7—Use of the agile principles

The SPSS row data collectively indicate how the PLs perceive the importance of the agile principles at different stages of the IPN. The results provide the subsequent contribution of the study (C7): The execution and evaluation stages are correlated through the agile principles of 'Flexibility', 'Reflective actions', 'Incremental & iterative learning', and 'Enabling environment'. The planning and execution stages are correlated through the agile principles of 'Flexibility', 'Incremental & iterative learning', and 'Reflective actions'. The evaluation and planning stages demonstrate correlation with each other through the agile principle of 'Reflective actions'.

The results have been structured and presented in Fig 10. Here the thick lines show strong interconnections, while the thin lines show medium interconnections between the different project stages.

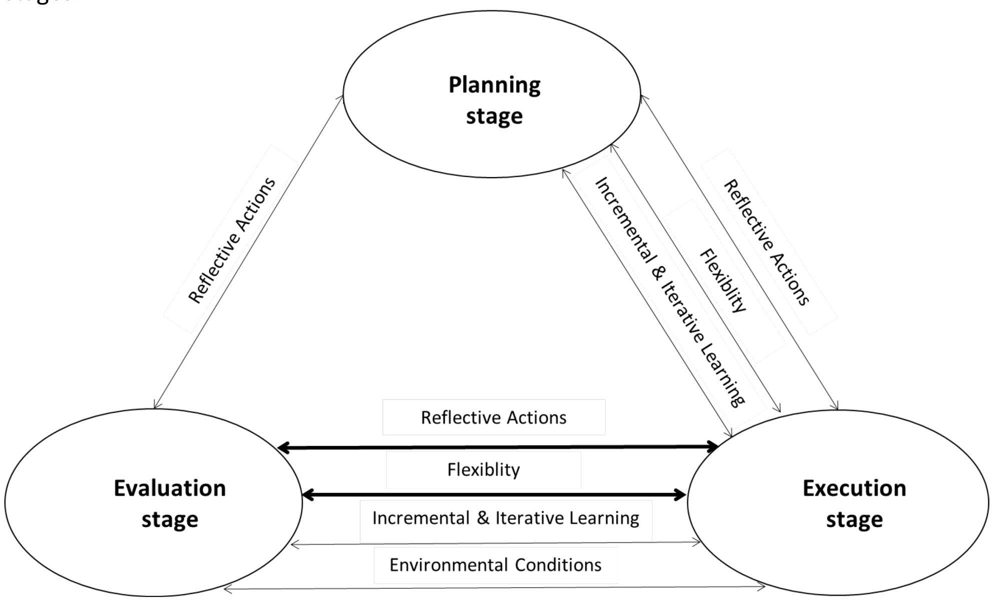

Fig 10. Agile principles showing strong and medium interconnections between different project stages of IPN

Additionally, factor analysis shows that 'Reflective actions' in the execution stage has the strongest correlation with all the other principles in all stages. Since 'Incremental & iterative learning', 'Flexibility', and 'Reflective actions' stand out as most important, we will now elaborate on the results in terms of each of these three principles.

The application of the 'Incremental & iterative learning' principle will support the IPNs by integrating each stakeholder's unique knowledge domain (Brown & Martin, 2015; Kazadi et al., 2016; Laine et al., 2015). Addressing stakeholders' knowledge in the execution stage will trigger examinations in the evaluation stage and adaptations in the planning stage. This feedback loop will help the project team navigate the project (Schulze et al., 2014). However, the PL will not use the 'Incremental &

iterative learning' between the evaluation and the planning stages. This means that stakeholders' innovative strategy will not benefit from the IPN since organisational knowledge creation requires transformation of knowledge learned at the project-team level to the organisational level (Nonaka et al., 2000; Nonaka et al., 2006). If the stakeholders do not expand their knowledge base through collaboration, they cannot contribute to IPNs to the full extent possible (Kapoor et al., 2016; Zahra & George, 2002).

The 'Flexibility' principle is about exploring, failing, and continuously developing new products or processes to ensure continuous adaptability to changing requirements (Conforto et al., 2014; Yannou, 2013). The results demonstrate how adaptation to changes made in the execution stage will be assessed in the evaluation stage and will consequently trigger a response in the planning stage. This feedback loop shows that the IPN will adapt to changes at the project-team level. However, PL will not use the 'Flexibility' principle between the evaluation and planning stages. This indicates that continuous changes in customer needs and technology development will not be considered during the project (A. B. Sandberg & Crnkovic, 2017). The detachment from organisational strategies will also not allow for reallocation of resources based on the changing needs of the IPN (Lazonick, 2005; West et al., 2014).

'Reflective actions' is the only principle that has strong and moderate correlations at all project stages. The principle is also strongly correlated to all the other principles within the execution stage, indicating the importance of enabling team dialogues, workshops, seminars, and informal and formal team platforms to discuss results, experiments, and models. The correlations of the 'Reflective actions' principle demonstrate that PLs emphasise the importance of inspections and adaptation of the working methods at the project team and the organisation levels (Derby et al., 2006; Nonaka et al., 2000).

The 'Reflective actions' principle stands out in the cross-correlations analysis of the principles as shown in Fig 11. Strong connections were found between this principle and 'Enabling environment' in the planning stage and between the execution and evaluation stages. These correlations emphasise that management should provide all necessary resources for the project team to work effectively and efficiently. Management should reflect on the changes that occur during the project and make necessary adjustments in the resources needed to run the project. From the knowledge perspective, time is one of the vital resources. Giving the project team enough time to work on a project is a precondition for people's will to invest time in building knowledge with others (Lazonick, 2005; Nonaka & Toyama, 2003; Reagans & McEvily, 2003). The evidence from previous studies shows that the projects in which the project team has insufficient time, display lower innovation than in projects where the team gets the necessary support from management (Maughan et al., 2013; Pertuzé et al., 2010).

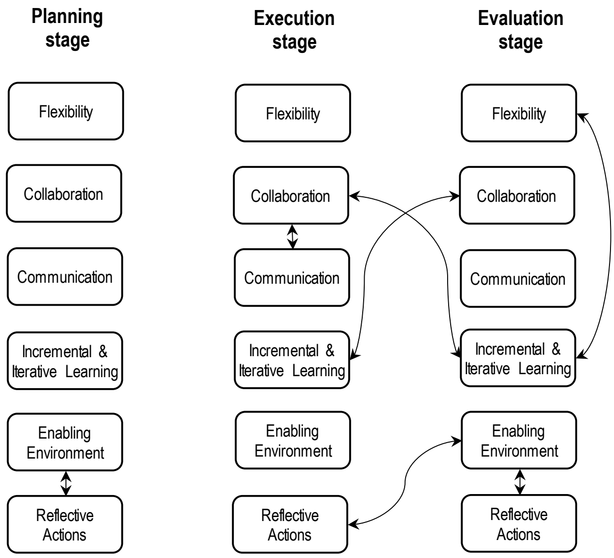

Fig 11. Cross-correlations of the agile principles in the three stages of IPNs

The lowest correlations among all the stages were identified for 'Collaboration'. However, in terms of cross-correlations, 'Collaboration' is strongly interrelated with 'Communication' in the execution stage. Interestingly, cross-correlations between 'Collaboration' and 'Incremental & iterative learning' were observed between the execution and evaluation stages. The agile principle 'Incremental & iterative learning' also has a strong interrelationship with 'Flexibility' in the evaluation stage.

4.3.3 Contribution 8—Differences between the industry and academia

The findings identify the agile principles perceived as more important by the industry than by academia, which provides the eighth contribution (C8) of the study: The industry perceives the agile principle of 'Enabling environment' in the planning and evaluation stages, and 'Flexibility', and 'Collaboration' in the execution stage as more important than academia.

The IPN and academic career require the academics to make the research public. This can course the different perception of 'Enabling environment' principle. Academics should dedicate considerable time to work on publications rather than ensure the implementation of research results. Meanwhile, the industry's concern is to facilitate project teamwork and make the IPN successful. 'Flexibility' in the execution stage is the other principle that is perceived to be more important by the industry than by academia. The industry is the owner of the project and must deal with any challenges that arise during the development process. Thus, integrating flexibility into the IPN is a major concern for the industry (Durney & Donnelly, 2015; Marchesi et al., 2007).

'Collaboration' in the execution stage is another principle that is perceived as being more important by the industry than academia. The industry is in charge of organising and facilitating the collaboration between the stakeholders on the one side and the project team on the other (Kazadi et al., 2016; Rigby et al., 2016a). The principle supports the development of their language and norms, thereby fostering a 'community of innovation' with its inherent socialisation context (Foss et al., 2011; Nonaka et al., 2000). The context provides for trust and mutual understanding, which are vital for collaborative knowledge creation and learning processes (Jacob et al., 2000; Laine et al., 2015). In this manner, the principle 'Reflective actions' helps industry and academia build similar knowledge bases and knowledge assimilation processes. The similarity is necessary to leverage knowledge learned from collaborative projects and to build long-term partnerships in R&I (Carayannis et al., 2000; Kapoor et al., 2016).

4.4 LIMITATIONS AND FUTURE RESEARCH

The thesis time frame puts some limitations on the study. Real-life application is needed to test if the proposed KM model can increase the value of I-A R&I projects. The studied type of project is 3-4 years long, which makes it impossible to examine the model on ongoing projects within the thesis duration. However, the proposed KM model extended by the agile principles can work as a tool for staging I-A R&I projects. It can analyse the operational situation for KM in such projects. Hands-on reviews of the agile principles by the industry and academia with other stakeholders within short time periods can modify management practices and make relevant changes in R&I development both at the operational and strategic organisational levels. Future research could involve conducting a programme, which collects critical parameters for knowledge processes, knowledge exploration, and exploitation of the project according to the proposed model. Moreover, comparing projects that use the model with those that do not would help to better comprehend the value of the proposed conceptual KM model.

5. CONCLUSION

The thesis aims to bridge the *valley of death* when research results from I-A R&I projects are not industrialised, by addressing this challenge from the KM perspective. The study concentrated on IPNs in the industrial sector in Norway. A literature review, case study, and qualitative and quantitative research supported the development of the conceptual KM model for I-A R&I projects. The proposed model is based on the Nonaka and Takeuchi KM model modified for the I-A context. Moreover, the thesis examines the use of the agile principles for the practical application of the proposed KM model to I-A R&I projects. Thus, the findings contribute to the I-A, KM, and agile KM fields.

First, the findings identify the critical factors that should be addressed by the KM model in I-A R&I projects. The critical factors are defining I-A R&I strategies and objectives as well as facilitating knowledge creation and learning processes. The findings show that the Nonaka and Takeuchi KM model with three modifications may address the critical factors. The Nonaka and Takeuchi KM model is based on the study of homogenous business organisations that collaborate in innovation for economic benefits (Ikujiro Nonaka & Takeuchi, 1995). The industry and academia are partners driven by different agendas and have unlike working approaches. Therefore, some adjustments of the model for the I-A context are required. These modifications are represented in the three dimensions of the Nonaka and Takeuchi KM model; that is, ontological, epistemological and time-dimension.

The first modification is the integration of the Nonaka and Takeuchi five-step organisational knowledge-creation process in three interdependent levels. These three levels are knowledge-creating entities on the *ontological* dimension of the KM model: each organisation's R&I strategy (level 1); I-A R&I strategy (level 2); I-A R&I project (level 3). Each level consists of the five-phase knowledge-creation process with a collaborative concept that addresses the critical factors in I-A R&I projects. The interdependency between the three levels supports the continuous improvement of the collaborative concepts at all levels of the KM model for I-A R&I. The lower levels function as an archetype for the levels above. In this way, the collaborative concepts on the upper levels go through the tests on the lower levels. Additionally, the interdependence between the three levels emphasises the importance of anchoring the project on the top management strategy. The interviews and observations during the qualitative study revealed that the involvement of the top management is decisive for further development and industrialisation of the project research results.

The other modification of the Nonaka and Takeuchi model takes place on the *epistemological* dimension. This dimension is where knowledge conversion takes place between the tacit and explicit. The collaborative concepts in each level support four modes of tacit-explicit knowledge conversion: socialisation, externalisation, combination, and internalisation. The collaborative concepts with specific management practices constitute the second modification of the Nonaka and Takeuchi model. The management practices address the critical factors in the I-A R&I projects; that is, they facilitate the combination of the DUI and STI modes of innovation while tacit-explicit knowledge conversion takes place. The management practices enable effective interaction between the scientific and practical knowledge of the industry, academia, end-users of innovative solutions, technology integrators, and other stakeholders.

The third modification of the Nonaka and Takeuchi model for I-A R&I projects takes place in the time-dimension. It concerns the last of the five phases in the knowledge-creation process *cross-levelling* of knowledge. This phase is expanded to *knowledge exploiting* in the I-A context. This is because industry, academia and other stakeholders must exploit knowledge during the project to understand what is needed to optimise the R&I development. *Knowledge exploiting* helps improve collaborative concepts such that they address the critical factors in the I-A projects continuously. Continuous *knowledge exploiting* supports modification of the R&I goals, improvement of management practices that facilitate knowledge creation and accelerate learning. The findings highlight that incremental continuous *knowledge exploiting* increases the utilisation of new knowledge, not only by the project but also enables the transfer of knowledge from the present project to other ongoing and future projects. In this way, *knowledge exploiting* supports the movement of new concepts to on a new cycle of knowledge creation at a different ontological level. This interactive and spiral process occurs both within and between organisations.

All three modifications support the dynamic of the proposed KM model, such that it can address the critical factors in the I-A R&I project at any time. In this way, the model supports the implementation of research results from I-A R&I projects and, thus, contributes to bridging the technological *valley of death.* Moreover, the model shows how organisational knowledge creation in the industry and academia upgrades itself through collaboration in R&I. The dynamic nature of the model reflects the interaction of the knowledge spirals along the epistemological and ontological dimensions over time. Innovation emerges out of these spirals (Ikujiro Nonaka & Takeuchi, 1995).

The model was verified throughout the study in workshops and by statistical validation and reliability tests. However, the real contribution of this work can only be evaluated through a comparison of the actual innovation project before and after applying the proposed approach. The duration of the IPN is 3-4 years; therefore, it is not realistic to execute real-life verification within this thesis period. Alternatively, a test of the model can be a subject for future research. Moreover, one should develop criteria for comparing the innovation impact of as many projects as possible with or without employing the model as this would be the best validation method. However, this would entail a significant amount of work and it would be necessary to ensure validation quality. The findings related to the applications of the agile principles to the proposed KM model can be a start for future research.

The study contributes to the knowledge of agile principles application in I-A R&I projects in the manufacturing industry. The findings identify the correlations between collaborative management practices and agile principles. The correlations suggest that agile principles can potentially be used as guidelines for the improvement of management practices. The correspondence can become the foundation for an effective management tool for I-A R&I projects. Moreover, the study identifies the correspondence between the agile principles, which the PLs perceive as the most important for the IPNs. The correspondence between the agile principles illustrates where the *knowledge* *exploiting* processes should occur according to the PLs; that is, what collaborative concepts at which stages require constant evaluation. Most of the correlations that are not prioritised by the PLs accentuate a shortage of *knowledge exploiting* processes between the project level and strategic level. Not applying new knowledge from the project at the strategic level, and vice-versa, does not contribute to organisational knowledge building and innovation (Ikujiro Nonaka et al., 2006). Therefore, the lack of correlation between the agile principles should be investigated in future research. Additionally, the study shows that the agile principles are perceived differently by the PLs from the industry and academia. These differences can indicate the expectations from both sides and help the partners to align their interests and the working methods in collaboration with R&I. This, in turn, will contribute to better results for I-A R&I projects.

Overall, using the proposed conceptual KM model combined with the agile principles can support the industry and academia in more effective and efficient collaboration in R&I. Indeed, the model implies an instant response to the changes that occur inside and outside the project. Rapid technology development, changes in the market, knowledge gained from prototype building should be instantly taken into consideration at all the organisational levels and project stages. As the study shows, new knowledge from the project can set out new R&I directions in the industry and academia strategies. Moreover, the other way around, knowledge coming from outside the project impacts the project development. The changes will require adjustment of the resources and collaborative methods. According to findings, this dynamic loop of the modification of knowledge creation and learning processes at all the organisational levels and project stages is what any R&I project needs to stay viable and ensure integration of the research results in an industrial setting.

It is believed that the proposed conceptual KM model has potential to support knowledge managers in industry and academia in conducting innovation projects more effectively and efficiently and deliver greater innovation value to partners and society. The model can also assist national and federal research/innovation councils in decision making when assessing industrial research project applications.

6. REFLECTION

At last, I would like to reflect on my role as the researcher and my own contribution in this collaborative research.

I was lucky that my colleagues were researchers that were deeply involved in the IPN project. I was sharing an office with one industrial PhD whose research work was a part of the IPN project. One of my supervisors was the project leader for this IPN project. This supervisor and the Ind PhD student had discussions about the project very often. In this way, I had the opportunity to be involved in the daily operations of the IPN project, and even test out my thoughts and insights regarding the research with colleagues. I also participated in the project workshops in the university and in the industrial company.

This is the background to both colleagues becoming co- authors in one paper, and one of them (the supervisor) becoming the co-author in all papers.
When it comes to the five conference papers, I was collecting and analysing all the data for the literature and qualitative studies. These papers were written solely by me, but the co- authors contributed to the discussions on interpretation of the data, research findings, and the language and structure of the articles. The co-authors had strong academic and industrial backgrounds, and their contribution significantly lifted the quality of the thesis work.

The journal paper was a more comprehensive paper, covering the results from the quantitative study, which was combined with the agile approach, and the survey for the project leaders. I had less experience with such quantitative studies. I designed the questionnaires for the study, and collected all the data, but I had some help with the technical handling of SPSS. The most difficult part of this paper was the interpretation of the correlation analysis. Here, I worked a lot with the discussion section and benefited from insights from the co-authors. However, I am still elaborating the discussions we had here, and I feel there are still unexplored tracks. The survey was comprehensive, and many analyses can be done from the database we collected. I now realise that the journal paper could have been divided into two separate papers. The first paper should have covered the development of the model and items used in the survey, and the second paper should have covered the survey, the results and the discussion and interpretation of the survey. With a two- paper structure, it would probably have been easier to discuss and interpret the results.

I would like to reflect on the factors that had an impact on my research.
For me, daily collaboration with the colleagues in the IPN project was motivating and engaging and gave me crucial insight into real industry-academia collaboration, at least in these specific projects and with these specific industrial companies. It is possible that this close insight into single projects, made me biased, leading me into specific directions in the research work. However, I was aware of that risk and tried always to have an open mind during the research study.

The travelling related to the research work helped a lot to broaden my worldview and expand my understanding of industry-academia collaboration.
For instance, the research group went to Singapore- one of the biggest innovation hubs, where leading universities and companies from all over the world collaborate in research and innovation. There we visited several universities, industrial companies, and incubators for innovative start-ups. The industry-academia collaborative models used there led to outstanding innovative outcomes, which inspired us a lot.

We got to know the different industry-academia collaboration models when we visited Nottingham University and the Coventry Manufacturing Center, in England. According to the researchers that work there, it was critical that research targeted the demands of industry.

The other perspectives on industry-academia collaboration were introduced in the workshops arranged by the university-industry innovation network (UIIN). It is an international organization with academic and industrial members from all over the world. The UIIN goal is improvement in university-industry collaboration in research, practice, and in policy.

All this international experience gave me different perspective on industry-academia collaboration and has certainly influenced the way I thought when collecting and analyzing the data in this study. Moreover, the courses I took as a part of the PhD program, increased my knowledge of existing theories. I was very much inspired by the Design Thinking approach to innovation, which was introduced in one of those courses.
The involvement of product users and importance of prototype building are vital for any collaborative product development. Therefore, I would recommend exploring application of the Design Thinking approach for future research on industry-academia collaboration in research and innovation.

We have used the knowledge acquired from this thesis in other projects in the university. We have applied the concepts for industry-academia collaboration to develop the university manufacturing laboratory (Manulab). Manulab aims to build engineering competence in production, applying the Industry 4.0 technology. Here we have integrated both academic and industrial knowledge in accordance with the thesis findings. That supports us in working together with industry in research and innovation projects and strengthens engineering education in the university.

It is worth mentioning that the usefulness of the thesis findings is confirmed by my colleagues. According to them, they use the identified management practices as the guidelines that support them in industry-academia collaboration. Colleagues have found especially useful the following findings: 1) the importance of engagement and support from the top management both in the university and the industrial companies, 2) the need for collaborative practices on three organizational levels, 3) the need for long term strategies for industry-academia collaboration.

However, the findings from this thesis provide the starting point for a bigger study on industry-academia research and innovation projects. The research results should be tested in real life. It requires three to five years based on the time period of the project, plus time for completing applications for research funding. The application of the model in real life is very much in line with what this research is about: the necessity of applying research results in real life to overcome the technological ‘valley of death’.

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APPENDIX I: MAIN PAPERS

MAIN PAPER 1

KNOWLEDGE MANAGEMENT OF UNIVERSITY-INDUSTRY COLLABORATION IN THE LEARNING ECONOMY.

Authors: Hansen, I. E. (main author), Mork, O. J., & Welo, T.

Proceedings of 2017 2nd International Conference on Knowledge Engineering and Applications (ICKEA)

Abstract. Rapid transformation of technologies and markets challenge organizations to build structures and norms that promote learning and innovation. Up until now, however, knowledge management has not been a common subject for investigation of university-industry collaboration in innovation projects. The few known studies have concentrated on the numbers of patents, spillovers and publications, or institutional set-up on the success of collaboration. The scientific community has paid little attention on how to leverage learning and knowledge creation in university-industry innovation projects, thus increasing their innovation impact on both organizations and society. This article addresses knowledge management collaborative university-industry projects and proposes a relevant knowledge perspective to stimulate outcomes.

Keywords: knowledge management; learning organization; organizational memory; university industry collaboration; innovation projects

I. INTRODUCTION

To generate new products, processes or technologies, companies are looking for ideas outside their organizational boundaries [1]. Collaboration with universities allows companies to acquire new knowledge that can improve their organizational performance and competitiveness [2][1]. Research projects, technology transfer, research consultancies are all different forms of university-industry collaboration (UIC). When using external knowledge for internal innovation, organizations have to absorb the new knowledge. Knowledge becomes obsolete much faster than before, which emphasizes the need to learn and to create new knowledge in a fast pace, challenging knowledge management to build organizational forms that promote learning and innovation [3].

The role of individual capabilities and interdependence between individual and organizational components is a key factor in innovation processes, meaning that organizational practices should support individuals to become more effective innovators [4] [5] [6]. When it comes to knowledge management of UIC projects, there is a lack of practical guidance to support individuals from different 'worlds' in co-creation of knowledge and innovation, thereby developing the absorption capacity of both organizations [7] [8] [9].

The other issue motivating more research is the importance of incremental innovation that takes place in university-industry collaborative projects. The majority of the research done on university-industry partnerships has concentrated on the so-called STI mode of innovation, where innovation is a result of industrial integration of universities' scientific technological knowledge. The importance of DUI mode—innovation based on doing, using and interaction—has been underestimated [10] [11]. This kind of innovation is typical for operators when dealing with problems in their daily operations. It is mostly undertaken in applied research and development and has incremental character. However, it happens more often than radical innovation grounded in basic research, and has a significant impact on the growth of the whole economy [12].

To answer the research questions posted in this article, we performed a literature review seeking to find evidence on (best-) practices in collaborative university-industry innovation projects. Such a literature review establishes the current state of the art in the field while highlighting potential issues that require more research. Thus, this paper addresses the identified need of studying how to more efficiently and effectively manage innovation processes in collaborative research projects. The paper comes with the research objectives aiming to design a practical approach for management of UIC projects with knowledge transformation in focus.

To enrich the understanding of the aspects that need investigation, next sections will present the challenges faced by university and industry in innovation projects. Each challenge is deliberated from the knowledge perspective. The research questions and a brief outline of the research plan are introduced in the last section along with a discussion.

Table I summarizes the challenges, questions and focus areas of the invoked research on university-industry collaboration from the knowledge management perspective.

TABLE I. CHALLENGES, QUESTIONS AND FOCUS AREAS OF THE INVOKED RESEARCH ON UNIVERSITY-INDUSTRY COLLABORATION FROM THE KNOWLEDGE MANAGEMENT PERSPECTIVE

Challenge	Research Questions	Research Focus
1. University-industry collaboration strategies and objectives	How to define a strategy for UIC in innovation projects such that collaboration will continually boost the knowledge base of both partners in a long -term perspective?	• Allocation of the resources, skills and efforts of the people, in the organizational learning process. • How to encourage individuals to believe in the values of collaborative research efforts, and boost social and emotional ties between people.
	How to define project objectives such that they meet both academic and industrial requirements while facilitating innovation?	Define the projects objectives and the results in terms of new knowledge acquired and the degree of implementation in industry.
2. Facilitating university-industry innovation projects	How to facilitate projects to enable knowledge creation and innovation?	Structural and social conditions that support interactive learning externally, across organizations, and internally, across organizational levels. The areas that research should concentrate on: a) UI boundary management: how to trigger and coordinate knowledge creation process and how to disseminate knowledge between organizations and across organizational levels. b) Creating the learning environment that will: • Increase individual creativity. • Provide common language and build trust and commitment. • Support interactions between tacit and explicit knowledge, between individual and collective learning.
3. Accelerating th e rate of learning from project to project	How to accelerate the rate of learning from each UIC innovation project?	Investigate managerial mechanisms that are needed to organize organizational memory such that people in UI project teams are able to acquire, store and retrieve knowledge.

I. CHALLENGE 1: UNIVERSITY-INDUSTRY COLLABORATION STRATEGIES AND OBJECTIVES

The challenge to manage university-industry (UI) innovation projects is rooted in fundamental differences of partners' logics. Universities' openness contradicts with the protective attitude of companies and creates problems in regards to intellectual property rights [13] [9]. Another factor is conflicting objectives of collaboration and different time horizons, where industry is looking for tangible short-term outcomes and academia is interested in publishing.

This paper argues that research on UIC innovation projects should turn its focus on how to support the processes of learning and knowledge creation in all phases of innovation project—rather than measuring the inputs such as motivation factors for collaboration, or outputs such as number of patents and the like. This will optimize knowledge exchange and co-creation processes in projects and intensify their innovation impact.

When university and industry collaborate in an innovation project, they create a collaborative unit that can be considered as one innovative enterprise with its own 'strategic control' and 'organizational integration' as some of the key social concepts. Here the 'strategic control' means a set of relations that gives executives the power to allocate resources to confront uncertainty of innovation [3] [5]. Allocation of resources implies 'organizational integration' of the skills and efforts of the people in the organizational learning process [3]. Hence, the study should explore how the university and company can align their research strategies and allocate resources to innovation such that collaboration will continually boost the knowledge base of both partners in a long-term perspective.

The innovation is uncertain and it is difficult to be sure about the results of innovation processes [5] [3]. It is thus challenging to define the UIC project objectives especially when partners have distinct interests. Both academic and industrial benefits should be derived from the project. Nonetheless, innovation is a dynamic process with learning as outcome, and it is of common interest for both partners [3]. Therefore, the research should investigate if the UIC innovation project objectives and the results can be defined in terms of new knowledge acquired and the degree of implementation in industry (See Table I).

II. CHALLENGE 2: FACILITATING UNIVERSITY-INDUSTRY INNOVATION PROJECTS

It is proven that structural conditions, formal and informal incentive systems, norms for internal and external collaboration are crucial for learning and innovation processes [14].

Different forms of collaboration between university and industry require different support structures and motivation mechanisms [9]. Therefore, we introduce the context of the research that this article stresses.

The research will find place at Norwegian University of Science and Technology, campus Aalesund, which is located at the west cost of Norway. Marine and maritime industries are dominating in this area, but there are also other industries represented. Shipbuilding companies, fish factories, furniture and food producers are some examples of industries present.

The study will investigate how the university cooperates with local companies in innovation projects, limited to 3 year duration period and restricted to mechanical engineering and industrial design. The incremental innovation typically undertaken in applied research and development is of research interest rather than radical innovation that is more common in basic research [12]. The two types of innovation have their origin in different types of knowledge, tacit and explicit. This will be explained and clarified in the following section.

A. Tacit and Explicit Knowledge

The traditional definition of knowledge is 'justified true belief'. He or she creates knowledge by making sense of the information in the given situation. This individual knowledge creation process is anchored in personal beliefs and perceptions of the world.

Knowledge can be explicit and tacit [15] [16]. Knowledge becomes explicit, or codified, when it communicated to others in the forms of sentences, documents, drawings and as such. Tacit knowledge is not easy to convey because it is tied to personal physical and emotional experiences, such as skills in bodily movement, intuitions and life values [17]. Individual creativity, which is a key factor for innovation, is connected to tacit knowledge [4] [18]. Tacit knowledge of operators is often critical for incremental innovations [12] [11]. Due to the nature of tacit knowledge, it represents a challenge for management to capture, transform and (re)use.

B. Social and Structural Conditions for Innovation

The actual learning process is the relation between tacit and explicit knowledge, between individual and organizational capabilities [3]. Management's task is to create appropriate structural and social conditions that would support these interactions [5]. The different phases of an innovation process demands appropriate conditions. Kanter has pointed out four innovation phases: "(1) idea generation and activation of the drivers of the innovation…; (2) coalition building and acquisition of the power necessary to move the idea into reality; (3) idea realization and innovation production…; (4) transfer or diffusion, … the commercialization of the product, the adoption of the idea" [5]. Kanter suggested structural arrangements and social patters that organization can apply to facilitate each of the phases. These suggestions imply interaction between people with different knowledge, skills and capabilities to perform successfully each innovation task. Kanter's recommendations are applicable to a company with a commercial mindset, but they should be adjusted for the use in the setting of UIC in innovation projects.

The barriers to successful innovation in university-industry research projects are similar to those that large firms face. Different divisions of a large company are like different 'thought worlds' where individuals organize their thinking and actions in relation to innovation in their own way, so called 'interpretive schemes' [19]. The same situation is relevant for UIC, where academics and industry think in distinct different ways. It brings us to the idea of creating the context—or environment that can support interaction between to different worlds—between tacit and explicit knowledge, between individual and collective learning.

C. Knowledge Enabling Context for University-Industry Innovation Projects

The idea of the context, or 'ba', came from Japan and stands for shared space that fosters knowledge creation. It can be physical, virtual and even mental meeting places where people share their personal values and beliefs; where they exchange and co-create knowledge. Social informal meetings, face-to-face discussions of the product's concepts or building a physical or virtual prototype are examples of knowledge enabling context [20] [21]. The essence is that knowledge needs a place to be created because knowledge is dynamic and is formed in continuous interaction between people and organizations and, thus, relying on the situation and people involved [18] [17].

When new ideas are generated by some of the members of UI project team, they must be shared with other project team members and, sometimes, to people outside of the project team. To be assessed by others, the ideas must be translated into the form others would understand [6]. In this case, for example, physical or virtual prototypes can provide a common language [22].

Social face-to-face meetings between individuals involved in a project contribute to trust building, which in turn has positive effect on interactive learning and risk taking, which are crucial components of creativity and innovation [23] [24] [25].

Hence, management of UI innovation projects should think appropriate learning contexts, or learning environments that will increase individual creativity. This context should provide a common language and build trust and commitment, which are the preconditions of the successful collaboration (See Table I).

D. University-Industry Boundary Management

The project manager of innovation projects between industry and university is usually a person from the company. A representative from the university has also a responsibility for managing the project on behalf of the university. Both managers act as 'gatekeepers' between the UI project team and their organizations, including departments directly involved in the project and other departments across organizations. Other industrial and/or academic partners are often involved in the project in order to contribute with their expert knowledge. Therefore, managers have to cope with many relations. In practice, there is always a challenge for companies to devote personnel to manage alliances. Especially projects that involve tacit knowledge require considerable managerial resources [12].

From the knowledge perspective, the two managers have the tasks to trigger and coordinate knowledge-creation process. They act as 'scouts' that have responsibility to mobilize broader participation both in generation and justification of the concepts [26] [5]. The managers have to ensure that internal users of the new solution are involved such that they feel an ownership to the project and thus contribute to the development and adaption of the idea [27].

Managers must be also 'ambassadors' that transmit knowledge to others outside the project team [26] [5]. Globalization, or dissemination of knowledge across many organization levels, is instrumental in inducing of organizational learning [17].

The diversity of external and internal participants, tightness of the relationships and cultural norms within these networks are the contextual characteristics that are likely to influence innovation processes and learning capabilities of partners involved [28].

These arguments call for research on the social and structural conditions that management of UIC innovation projects should provide to facilitate interactive learning across organizations and enhance absorptive capacity of the partners [7] [5] [8] [9].

It is also important to investigate the social conditions in relation to strategy of UIC innovation projects. Specifically, the researcher has to look into how to encourage individuals to believe in the values of collaborative research efforts, and boost social and emotional ties between people [5] (See Table I).

III. CHALLENGE 3: ACCELERATING THE RATE OF LEARNING FROM PROJECT TO PROJECT

Learning from project to project means not only storing the knowledge about previous projects, but also transforming, generalizing and making it accessible to others and being able to retrieve it in new projects.

Hargadon and Sutton studied one of the largest and successful product design firm in United States, IDEO. Researchers defined IDEO as a technological broker, implying that the success of the firm depends on the firm's network position and organizational memory that allows acquiring, retaining, and retrieving new combination of knowledge obtained through its position in a network [29] [14].

Hargadon and Sutton claim that the organizational memory relies on individual actions and organizational routines in recognizing, storing, blending and transforming knowledge. IDEO deliberately employs workers that have working experience and hobbies different from background to other designers who already work in the company. IDEO's organizational norms proclaim that personal knowledge of designers has to be accessible to others in order to be retrieved for new solutions. Displaying individual knowledge in physical objects and prototypes, participating in the routine brainstorming, having open-office lay outs are some of the methods company has integrated in order that everyone in the company knows what the others are experts in and can dynamically co-create new products and technological solutions [14].

Future research on UIC innovation projects can use the IDEO-perspective of organizational memory to investigate how UIC can accelerate learning in both organizations from project to project. The study should focus on what managerial mechanisms are needed to organize organizational memory such that people in UI project teams are able to acquire, store and retrieve knowledge (See Table I).

IV. DISCUSSION

This situation invokes the research on innovation projects between university and industry targeting the following research questions:

- How to define a strategy for UIC in innovation projects such that collaboration will continually boost the knowledge base of both partners in a long-term perspective?
- How to define project objectives such that they meet both academic and industrial requirements while facilitating innovation?
- How to facilitate projects to enable knowledge creation and innovation?
- How to accelerate the rate of learning from each UIC innovation project?

The article has defined the areas that research should focus on in order to answer those questions from the knowledge management perspective (See Table I). Both academic managers and company managers with experience in university-industry collaboration will be consulted for interviews. Their opinions and suggestions should provide the solutions to the challenges presented in the article [30]. The research plan consists of three steps:

- Semi- structured and informal interviews of managers and academics on how they experience collaboration and how they would like it to be.
- Analyze interviews and synthesize the results in practical guidelines for managing the UIC innovation projects.

• Test practical guidelines via interviews or workshops with participants from university and industry.

The presented research is relevant for academics, industrial companies and policy-makers. Policy-makers are interested in increasing the innovation impact of academic research on industry. For industry, collaboration with academics is different from collaboration with customers, suppliers, or other business companies. Entering partnership with academics, the industry has to consider the need of academic outcomes. Therefore, policy-makers should establish a set of guidelines helping academic and industrial partners to execute innovation research projects in a way that brings innovative outcomes and strengthens the 'knowledge-based' society [9].

When the management—either of universities or industrial companies—is equipped by practical tools to conduct innovation projects more efficiently, it is more willing to engage in more projects and is thus capable of developing skills in managing collaborations, as well as increased awareness of new projects and reputation as a valuable partner [31]. In addition, the positive outcome of innovation projects will most likely trigger new projects with the same partners, because it is easier to mobilize people and resources in a cohesive network where it is greater trust and already functioning norms and processes for collaboration [25].

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MAIN PAPER 2

MANAGING KNOWLEDGE IN MANUFACTURING INDUSTRY - UNIVERSITY INNOVATION PROJECTS.

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Abstract. Nowadays, manufacturing companies collaborate with universities in innovation projects to sustain or achieve competitive advantage. However, fundamental differences between the industrial and academic worlds hamper the utilization full innovation potential of such collaboration. As a countermeasure, industry stresses the need for the development of knowledge management tools that can increase the value of collaborative innovation projects. This paper covers a qualitative study of research-based innovation projects owned by manufacturing companies and partly funded by government, where the academia has the role as research provider. We seek to answer two research questions: (1) how can the strategies and objectives for collaboration to meet both partners' expectations be defined? (2) how to facilitate the projects to enhance the creation and exploiting of knowledge? The study identifies that a modified version of Nonaka's so-called five-phase model of organizational knowledge creation is applicable for the given context. Based on this, we propose a conceptual knowledge management model of university-industry collaboration in innovation projects. The proposed model provides (1) management initiatives that intensify knowledge creation and exploiting processes (2) ensures partners' commitment to collaboration along with the continuing improvement of university-industry collaborative concepts. It is proposes that the model will support knowledge managers of industry and university in conducting innovation projects more effectively and efficiently, as well as deliver even more innovation values to partners and society. The model can also assist national and federal research/innovation councils in decision-making when assessing industrial research project applications.

Keywords: Industry-University Collaboration, Knowledge Management, Innovation Project.

1. INTRODUCTION

Research-based innovation projects between industry and university leverage competitiveness in the global market, while providing scientific knowledge and value for society. However, substantial differences between manufacturing companies and universities hamper collaboration, often leaving innovation potential from projects unexploited (Perkmann et al., 2013). Industry stresses that the use of knowledge management tools will enable more and better quality results from innovation projects with universities (I.-E. Hansen et al., 2018). This study aims to contribute to the understanding of this challenge by answering two research questions that target the main challenges in University-Industry Collaboration (UIC) projects: (1) how can strategies and objectives to meet both partners' expectations be defined? (2) how to facilitate the projects to amplify the creation and exploiting of knowledge. This study encompasses university-industry (UI) innovation projects that are owned by industry and partly funded by government, where academia has the role as 'external' research provider. The companies studied herein are characterized by mechanical production in marine and maritime businesses; including producers of propulsion systems, shipbuilders, manufactures of equipment for fish factories and similar. Within this industrial context, innovation occurs typically due to solving specific industrial problem based on tacit knowledge acquired from work experience, often through learning-by-doing, using and interacting, i.e., a so-called DUI-mode of innovation (B.-Å. Lundvall, 2006). This is an important research topic since most existing UI studies are done on the scientific-technological type of innovation (STI) process in which innovation is invented by researchers for industry, and not the result of the joint activities between industry and university.

The qualitative research conducted herein identifies that Nonaka & Takeuchi's model of organizational knowledge creation is applicable to the UI context (Ikujiro Nonaka, 1994). Based on that and a somewhat modified version of their model, we propose a conceptual model of knowledge management of university-industry collaboration in innovation projects. The model aims to intensify knowledge creation and improve exploiting processes. The authors believe that knowledge managers of industry and university can use this model as a practical guideline to execute innovation projects more effectively and efficiently, thus increasing innovation impact. Moreover, the model can support national and federal research/innovation councils in decision-making when assessing industrial research applications.

The reminder of the article is organized as follows: The next section (2) introduces the theoretical background. Section 3 presents the research methodology employed. The research findings are summarized in Section 4 and followed by a discussion in Section 5. Section 6 gives conclusions and further work.

2. THEORETICAL BACKGROUND

The acknowledged organizational knowledge creation model is introduced by Nonaka & Takeuchi (Ikujiro Nonaka, 1994). It consists of five phases: sharing tacit knowledge, creating the concept, justifying the concept, building of an architype and cross-leveling knowledge.

The project team starts with *sharing tacit knowledge*. People share knowledge they acquired through personal experiences in the specific knowledge fields. For instance, the technology integrator can provide insights into feasibility of the technology integration in factories. Based on the ability to share tacit knowledge team members *create a concept* of a new product, process or service. The created concepts must be justified against criteria identified by knowledge goals and the needs of society. *Justifying the concept* often involves experts outside of the project group. Ones the concept is justified, it must be tested by an archetype. The last step, *cross-leveling of knowledge*, implies the sharing of knowledge derived from the project with the rest of the organization. Cross-leveling triggers new cycle of knowledge creation forming a spiral process accentuating that organizational knowledge creation is a continuous and process.

3. METHODOLOGY AND BACKGROUND FOR STUDY

The study covers the so-called ‘user-driven research-based innovation’ type of project. ‘User’ is an industrial company, which typically submits an application to the Research Council for financial support (*Research Council of Norway*, 2019). The Research Council (RCN) of Norway provides financial support for collaboration between industrial companies and research organizations to promote innovation and sustainable value creation through research-based innovation. RCN stimulates industry to innovate and mitigates the risk of innovation by covering around 40% of the cost of such projects. Typically, most cash funding for external academic research in such projects is funded by RCN. The company contributes in-kind (hours and equipment), some cash funding and acts as a contract partner with RCN for such projects and is therefore responsible for the project and its budget.

The context for this study are the manufacturing companies and a university campus located on the west coast of Norway. The size of the companies and their R&D capabilities vary significantly. There are some large companies with plans for research many years ahead, they are the ones that comprise their own basic research. However, the majority of companies are smaller with significantly shorter research horizons. This work focuses on two research questions: (1) how to define goals for collaboration to meet the expectations of industry and university, and (2) how to facilitate projects to amplify knowledge creation and exploiting. Fifteen individual semi-structured interviews were conducted. The respondents were six academic project managers, six industrial projects managers, two academic PhD candidates, and one PhD employed by one of the companies. Furthermore, the workshop with fourteen PhDs and two senior researchers was arranged to collect input to the study. The first and second authors of this paper facilitated the workshop. Moreover, seven observations of an ongoing project, including formal and informal meetings combined with nine semi-structured interviews were conducted as a part of this study.

4. FINDINGS

The collected data was used to create a new knowledge-management model of UI collaboration in innovation. The proposed model reflects the necessity of several aspects to support the knowledge creation process in the UI context—ones that are not considered by Nonaka & Takeuchi’s model: (1) commitment of resources, (2) managerial initiatives that support not only the creation of knowledge, but also its exploitation.

Commitment of dedicated resources to the project is one of the major tasks in managing UI projects (I.-E. Hansen et al., 2018). Therefore, the proposed model is organized at three interdependent levels; i.e., each organization’s strategic level, UI collaborative strategic level, and UI project level as shown in Fig. 1. Integration of the project level into UI collaborative level and integration of the latter into top-management level reflect the necessity of top-management to support and prioritize the projects by allocating them sufficient resources, even in competition with operational needs and daily business.

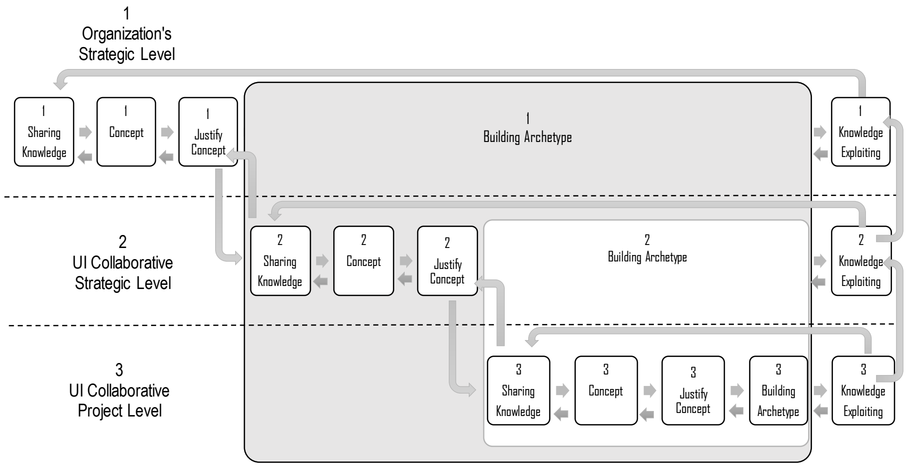

Fig. 1 *Conceptual model of knowledge management of UI innovation projects*

Exploiting knowledge in innovation projects is a major concern. Even when the projects generate new ideas, they are not always used in ongoing project. To accentuate the importance of this aspect, the last phase in UI collaboration model is formulated as 'knowledge exploiting'. Table 9 presents conceptual solutions that collectively support knowledge exploiting by answering the research questions on how to identify collaborative goals and facilitate knowledge processes. The collaborative concepts emerged from the data analysis. The scrutiny of the data from interviews and observations led to categorizing data into collaborative concepts on three levels: each organization's strategic level, UI strategic level, and UI project level.

The model incorporates continued improvement of collaborative concepts. Fig. 1 shows that each organization's grand concept for collaboration in innovation is verified at the UI collaborative level. Here, the step 'building architype' on level one triggers the knowledge creation process at UI collaborative strategic level two. Both concepts go through the test on project level: the knowledge-creation process on project level three evaluates the quality of the concepts from the levels above. Thus, the project functions as an archetype of level one and level two. For instance, a constant shortage of resources from university and industry in the project would imply a revision of the collaborative concepts at all levels.

Table 9. *University-industry innovation projects: collaborative concepts*

Concept level	How to define collaborative goals	How to facilitate innovation
Organization's strategic level	Knowledge vision and strategy with national and regional directions for innovation	Dedicate and allocate resources for collaboration: PhD programs Industrial management and senior researchers support PhDs Interdisciplinary collaboration
UI collaborative strategic level	Building knowledge platform: long-term collaborative strategy	Clarification of partners' expectations Strategic UI project group: members are involved in many UI projects Absorptive capacity of involved: industrial and academic background
UI project level	Project objectives are aligned with UI collaborative strategy	Clarification of partners' expectations Anchoring the projects at top-management Industry should navigate the project Involve internal and external stakeholders Provide common language Create a momentum: keep enthusiasm

5. DISCUSSION

The study shows that the organizational five-step model of the knowledge-creation process introduced by Nonaka & Takeuchi can be applied to knowledge management in UI collaboration with some modifications. Modifications are consistent with the answers to the research questions: how to define collaborative goals and how to facilitate knowledge-creation and exploiting. The model contributes to UI collaboration by (1) providing collaborative concepts that intensify knowledge creation and exploiting processes, (2) ensuring the commitment of partners in collaboration and providing for the continuing improvement of UI collaborative concepts. In the following, each of these contributions will be discussed separately.

5.1. Collaborative Concepts for Knowledge Creation and Exploitation

The concept at each level of collaboration contains specific initiatives that provide creating and application of new knowledge thereby ensuring success of UI innovation projects. The contribution to each phase of the knowledge creation process are considered individually.

The Sharing tacit knowledge phase includes sharing experiences to enable sharing mental models. The involvement of people with backgrounds from academia and industry, such as senior researchers and highly educated industrial employees, helps partners to rapidly relate to each other. Integrating academic PhD candidates in a company's operational environment generates common experience with industry, making it easier to share tacit knowledge. University and industry knowledge strategies crystallize the multiplicity of shared mental models in one direction (Ikujiro Nonaka, 1994). The managerial initiative at project level creating a momentum by delivering a value in the beginning of the project quickly, generates positive collaborative experience and accelerates sharing of tacit knowledge. For instance, researchers can use their methodological tools to solve a few small industrial problems at the very beginning of the project.

Concept creation is about how the partners are going to collaborate in innovation. Table 9 depicts the concepts guidelines how to define the goals for collaboration in innovation and the initiatives to achieve these goals. Dedication of the resources for innovation project is the core of the Concept creation. In practice, partners should assign which knowledge contributors are required for the project and the adequate quantity of time they will use on the project. For instance, the project requires that one engineer uses 40% of their time, two days a week, to design the prototype and participate in prototype building. The mechanic and electrician each will use 20% of their time to work on prototype. The same concerns the university. The project manager on behalf of the university and the researchers from the required knowledge fields, for example, expert in automation and software developer will be assigned time they are required to use on the project. Dedication of resources is crucial for project success. Otherwise, daily routines will take over and UI innovation project will be given less priority. Concept creation implies also initiatives that support ‘shared language’. Avoiding academic terminology, use of industrial language, sketches, drawings, and mockups are the means that provide mutual understanding. The model emphasizes the role of the strategic UI project group that collaborates over time on many technological projects. Accumulating collaborative experience helps to execute the project more effectively.

Clarification of expectations in strategies and objectives supports Concept justification. This study suggests that the top management in university and industry has the main responsibility to incorporate justification criteria in organizational knowledge vision and strategy, which must be consistent with national and regional plans in research and development. The collaborative UI unit should establish a set of sub criteria in the form of a UI collaborative strategy for a long-term partnership, which is in line with the knowledge strategies of organizations. Consequently, the project objectives present the set of sub criteria that coincide with the justification criteria at the above levels. The research questions should be defined in line with the industrial needs and have some room for flexibility due to uncertainty in innovation projects. Involving stakeholders, people from different departments in companies and universities, end users of future innovative solutions, is vital for creation and justification of the concepts.

Building archetypes is a necessary part of creating a new process or new product. Rapid prototyping and frequent interactions with users are a prerogative for success. Additionally, a prototype is a great communication tool for people from different backgrounds. Using it frequently will improve communication between industry and academia and increase the quality of the knowledge creation processes.

Cross-leveling knowledge depends on university and industry committing resources to undertaking projects and implementing the results. The university should provide enough time for the researchers to be able to integrate new knowledge into educational programs and develop it further through other projects with industry. To ensure implementation of research findings in industry, one should actively involve company’s customers and/or operational users of new knowledge in the project. That will ensure that project will meet industrial requirements and make the company commit the resources to execute the project and implement the results. Moreover, the engagement of operational users in the project will give them ownership of new knowledge, creating willingness to use it. The study also emphasizes that integration of technology experts in the project ensures the feasibility of applying project results.

5.2. Commitment and Continuous Improvement of Collaborative Concepts

Fig. 1 illustrates the embeddedness of the project and strategic UI collaborative levels in the main knowledge creation process of each organization. This means that creating and exploiting knowledge at the project level need support from a collaborative UI strategic unit and the decision-makers at the top-level of each organization. Therefore, the grand concept at each organization's strategic level emphasizes the necessity of top-management commitment to collaboration. Without this, the basis for initiating a new project is lacking. The model's dynamic provides continuous improvement of collaborative concepts. The collaborative concepts at three levels function interdependently. Universities and industrial companies define their own grand concept for collaboration with others in innovation. The grand concept must support the concepts for collaboration at the levels below: the common UI collaborative strategy level and the UI project level. Modifications on each level of the collaboration trigger the optimization processes on the other levels. Continuous improvement makes the model dynamic.

5.3. Verification of the proposed Knowledge Management Model

The proposed model is newly developed. The first assessment of the theoretical model was made in the workshop with the participants from one accomplished UI innovation project. The project leader from the university, the PhD candidate and industrial PhD candidate who, during the project had to take over the role of the project manager on behalf of the company, evaluated the collaborative concepts. The criteria for evaluation was the degree of impact form the concepts' substances on the projects: low, middle and high. The participants assessed the concepts individually. They also discussed the formulation and content of the statements.

The participants saw the model's potential to help university and industry deliver more innovation. They asserted that the model could also be a tool for setting up new projects for further exploration and exploitation of knowledge derived from the project. The workshop results help the researchers to develop a more practical version of the model for implementation. Conversion of the theoretical model into practical guidelines will make it easier for knowledge managers of university and industry to apply and validate the model. The plan is to use focus groups to test if practical guidelines give meaning and are suitable for practical application. The focus groups will involve experienced project managers from university, industry and representatives from RCN. The true contribution of this work can only be evaluated through the comparison before and after applying the proposed approach to the real innovation project. In this connection, it is worth noting that this is a typically three-years long project and it would take long time to get the final results. Moreover, one should develop the criteria for comparing the innovation impact of the projects with and without employing of the model. As many projects as possible is the best for validation. However, one should be aware of the amount of work and necessity to ensure the quality of validation.

6. CONCLUSION

This research contributes to knowledge management theory by adapting the organizational knowledge creation theory of Nonaka & Takeuchi to the context of UI collaboration projects. In practice the model has a potential to support university and industry in conducting innovation projects more effectively and efficiently. The model provides the collaborative concepts on the three levels: strategic organizational, UI strategic collaborative level and UI project level. The concepts are the knowledge management initiatives that support creation and application of knowledge in innovation project. They encompass the specific recommendations of how to define collaborative knowledge goals and the activities to achieve them. The model emphasizes the importance of continued knowledge exploitation that triggers constant improvement of the collaborative concepts on all levels. The future research shall validate the effect of application of the model to the projects. Although the study covers mechanical engineering companies in marine and maritime sectors on the west coast of Norway, the issues between university and industry are common in other industries and alike for any private-public collaboration.

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MAIN PAPER 3

BRIDGING THE 'VALLEY OF DEATH': CAN AGILE PRINCIPLES BE APPLIED IN INDUSTRY-ACADEMIA RESEARCH AND INNOVATION PROJECTS?

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Abstract. Government funding supports industry-academia research and innovation projects in Norway, sharing the risk of the research component in innovation. However, funding alone may not be sufficient to overcome potential differences in collaborative agendas and ways of working. As a result, positive research outcomes often get stuck in the *valley of death*, instead of ending up as successful innovations that create value.

To contribute to bridging the *valley of death*, we investigated the importance of six agile principles for collaborative industry-academia research and innovation projects, abbreviated IPN in Norway. The study was limited to the manufacturing sector. We surveyed 124 IPN project leaders (70 from industry; 54 from academia) to evaluate the importance of the knowledge management practices associated with the six agile principles across the three project stages. The statistical analyses indicate the consistency of the agile principles throughout the project stages. This means that agile principles are relevant for IPN projects and can be used as guidelines for improvement of the knowledge management practices.

Moreover, the study identifies the agile principles that are perceived as most important to use in different stages of a project. It also identifies the different perceptions of the importance of agile principles of the project leaders from industry and academia. These findings can support project leaders who are implementing agile principles to industry-academia research and innovation projects.

The results from the study can also support national and federal research/innovation councils in decision-making when assessing industrial research applications.

Keywords: agile principles, knowledge management, industry-academia, research and innovation projects

1. INTRODUCTION

Governmental funding of collaboration between industry and academia in technology innovation is one of the ways to accelerate and scale up research and innovation (*European Commission*, n.d.). It allows industries to carry less investment risks, while providing access to a broader range of expertise and advanced technologies than they have in-house. For academia, such governmental funding schemes provide a great opportunity to develop new knowledge and stay updated on industrial needs, in addition to external funding, patents and licensees emerging from such projects.

However, governmental incentives do not guarantee any success of collaborative industry-academia research and innovation projects. Fundamental differences in agendas, ways of working, and time perspectives create barriers for collaboration and decrease projects' innovation potential (Ankrah & Omar, 2015; Galan-Muros & Davey, 2019; Perkmann et al., 2021). Even when industry and academia manage to collaborate effectively and achieve the results that are beneficial for industry, this is not always enough for successful technology realisation (Larsson et al., 2006; Perkmann et al., 2015). Lack of innovation outcomes is often linked to the so-called *valley of death*, which is a place where many of the results from industry-academia research and innovation projects end up (Maughan et al., 2013b). Bridging the *valley of death* requires new approaches to traditional project management (Hansen et al., 2017; Jonsson et al., 2015; Laine et al., 2015).

Previously, we conducted a qualitative research study that included a literature review, in order to gain understanding of the underlying reasons for innovation project challenges, and how to facilitate the projects to better achieve the research and innovation goals (I.-E. Hansen et al., 2017; I.-E. Hansen et al., 2018; I. E. Hansen et al., 2019; I.-E. Hansen, Mork, & Welo, 2019; I.-E. Hansen, Mork, Welo, et al., 2019). The study proposes management practices that can increase the innovation potential from industry-academia research and innovation projects. It is proposed that implementation of practices should be done in three project stages, including planning, execution, and evaluation. These management practices seemed to be associated with the agile principles, which are the fundamentals of *agile project management* (APM) (Highsmith, 2009). APM has proven to be very effective for innovation projects within software development (Rigby et al., 2016b). Nevertheless, due to its inherent focus on responding rapidly to changing conditions, APM has also dispersed into other areas like manufacturing, sales, and marketing (Conforto et al., 2014; Cooper & Sommer, 2016; Nelson, 2008; Rigby et al., 2016a; Rigby et al., 2018; Zhengwen Zhang & Sharifi, 2007). Agile development has also spurred interest in the research community within collaborative industry-academia projects, and several studies refer to beneficial use of the agile principles. However, the studies largely concern software development, thus necessitating a call for studies on the agile principles' application in other areas of product development (Marchesi et al., 2007; A. Sandberg et al., 2011; A. B. Sandberg & Crnkovic, 2017).

To contribute to this body of knowledge, this study explores project leaders' personal opinions about the importance of agile principles in industry-academia research and innovation projects in the manufacturing domain.

The remainder of this paper is organised as follows: Section 2 gives insight into the theory of APM and the knowledge gap concerning the application of agile principles to industry-academia research and innovation projects. Section 3 introduces the research objective and the research questions. Section 4 presents methodology and research design, including the data collection and analysis method. Section 5 presents the findings related to the research questions, while Section 6 discusses these results. Section 7 concludes the study.

2. BACKGROUND

APM has proven to be effective for projects targeting innovation (Rigby et al., 2016a; Rigby et al., 2016b). APM was inspired by the findings of Takeuchi and Nonaka published in the article 'The new new product development game' in 1986 (Takeuchi & Nonaka, 1986). The authors identified that the common reason for numerous successful innovations in Japanese companies was the new way of collaborating and organising product development. The inference was to 'stop running the relay race and take up rugby', implying that the traditional sequential project management approach cannot keep up with an instantly changing environment, and companies need to operate with self-organising, cross-functional teams that work with overlapping development phases. Later, in 2001, their findings together with other software development methodologies, lay the foundation for the Agile Manifesto (Highsmith, 2009). These methodologies were different, but they had a common ground – lessening and simplification of development rules for quicker adjustment to rapidly changing environments (Rigby et al., 2016b). The Agile Manifesto stated four basic agile values: individuals and interactions over processes and tools; working software over comprehensive documentation; customer collaboration over contract negotiation; responding to change over following a plan. Twelve principles were developed to support the agile values. The principles fulfil the following criteria (*Manifesto for Agile Software Development*, n.d.):

- deliveries of the working product within shorter time cycles;
- tight collaboration between developers and businesspeople;
- empowering motivated individuals and self-organising project team;
- encouraging face-to-face interactions between all stakeholders;
- reducing comprehensive documentation and quality defects.

There exist some studies on agile applications in industry-academia research and innovation projects. In the studies within software development in Sweden, authors identified several best practices related to the agile principles that were applied in successful industry-academia research and innovation projects (A. Sandberg et al., 2011; A. B. Sandberg & Crnkovic, 2017). The findings identified the importance of capability of projects to deal with fast-paced changing business environment. This implied that projects should address only the research questions that allow adjustment to changing industrial goals. Organising meetings for engineers and researchers as well as ensuring frequent deliverables to industry were also pointed out as determinants of innovation success related to the agile principles. The persistent practical deployment of the research results and the visible presence of researchers in industry were emphasised by other studies on agile in industry-academia software development (Grunbacher & Rabiser, 2013; Wohlin et al., 2012). However, as the existing studies are in the software development domain, there is still a lack of evidence regarding application of agile principles in industry-academia innovation projects, for example, in manufacturing industries.

3. RESEARCH OBJECTIVE, AND RESEARCH QUESTIONS

The previous study on industry-academia collaboration in research and innovation projects in the manufacturing sector identified several significant findings.

Fig 12 depicts the research framework beginning with a previous qualitative study, including a literature review, followed by a quantitative study (I.-E. Hansen et al., 2017; I.-E. Hansen et al., 2018; I. E. Hansen et al., 2019; I.-E. Hansen, Mork, & Welo, 2019; I.-E. Hansen, Mork, Welo, et al., 2019). The literature analysis from the previous study (Step 1) revealed the critical factors that should be addressed in the projects. These include defining collaborative goals, facilitating knowledge creation processes, and accelerating the rate of learning.

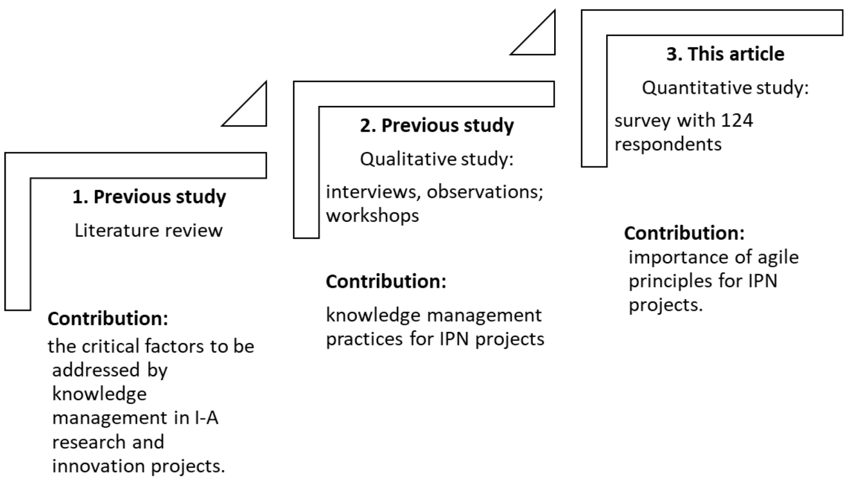

Fig 12. Research process

Subsequently, the qualitative research (Step 2) aimed to get a deeper understanding of what can be done to address the aforementioned critical factors in practice. The study concentrated on innovation projects in the industrial sector (henceforth denoted as IPN projects), in Norway. This choice was made because the IPN project is a well-established form of industry-academia collaboration. However, even as approximately 50% of IPN projects reports innovation success, there is still a great room for improvement (Bjørn G. Bergem, 2019).

IPNs are governmentally supported, research-based innovation projects between industry and academia, where the latter is typically a university or research institution. The project contract is between the Research Council of Norway (RCN) and the industrial company, while the academic institution is contracted to perform research within the project. The industrial company initiates the IPN and finances typically 60% of the total project costs through in-kind hours assigned to the project. RCN covers the costs related to the contracted research activities of the academic partner(s). An IPN project typically lasts three to four years and have an average total budget of 1.5 million EUR (*The Research Council of Norway. Innovation projects in industrial sector*, n.d.).

The data for the qualitative research was based on informal and formal semi-structured interviews of selected project leaders and PhD students with experience in IPN projects. In addition, the first author of this paper had the opportunity to observe colleagues who worked on an IPN project almost daily over a three year-period. This shows the researcher's prolonged engagement in the field being studied (Lincoln & Guba, 1986). Several workshops with the researchers participating in different IPN projects were also used to complement the findings.

The qualitative study proposed a conceptual knowledge management (KM) model for industry-academia collaboration in research and innovation projects. The model integrates the organisational knowledge creation processes of Nonaka and Takeuchi in the context of IPN project with several modifications (Ikujirō Nonaka & Takeuchi, 1995). The first modification involves the specific management practices that support knowledge processes in the three stages of an IPN project, namely planning, execution, and evaluation. The second modification involves the use of new knowledge obtained during the project for continuous improvement of management practices.

Nevertheless, the core of the proposed conceptual KM model for industry-academia collaboration in research and innovation is the Nonaka and Takeuchi model, which has proven to be among the more robust models in the field of KM. However, it has its shortcomings. The model focuses on the practices that support knowledge creation and learning processes, but it does not address the principles that help to refine these practices (Dalkir, 2017). Meanwhile, a closer analysis of the results from the qualitative research on IPN projects showed that the identified management practices have a lot in common with six of the agile principles. In agile project management, the agile principles help project leaders to improve management practices and thereby optimise new product development continuously (Highsmith, 2009). **Therefore, we decided to investigate if agile principles can do the same for IPN project leaders. Hence, the objective of this study is to investigate the potential of agile principles to support project leaders in the management of industry-academia research and innovation projects and to explore how the agile principles should be applied in different project stages.**

The starting point for the study is to check whether the use of the agile principles is relevant for IPN projects. Thus, the first research question (RQ1) is: ***Are the agile principles aligned with the management practices throughout the IPN project?***

If the consistency is confirmed, the next step is to investigate the use of agile principles in IPN projects. Therefore, the second research question (RQ2): ***How do project leaders perceive the importance of the agile principles in different stages of IPN projects?***

Since academia and industry have different agendas for collaboration in research and innovation projects, it is likely that the differences may be reflected in their perceived importance of the agile principles. This leads to the third research question (RQ3): ***How do project leaders from industry and academia perceive the importance of agile principles in different stages of IPN projects?***

4. METHODOLOGY

4.1. Data collection

Table 10 presents the six agile principles from the Agile Manifesto (*Manifesto for Agile Software Development*, n.d.), which we found to be in line with the management practices identified in the previous study (I.-E. Hansen et al., 2018; I.-E. Hansen, Mork, & Welo, 2019; I. E. Hansen et al., 2019; I.-E. Hansen, Mork, Welo, et al., 2019). 'Flexibility' implies instant adaptation of the industry-academia innovation projects to the commonly changing industrial needs. 'Collaboration' and 'Communication' emphasise the need for close interaction between developers, researchers, and end-users for increasing knowledge creation and learning. 'Incremental & iterative learning' focuses on building knowledge together with stakeholders. 'Enabling environment' means that the management shall create conditions for the project team to work effectively and efficiently on innovation. This implies ensuring a self-organised, multi-disciplined project team, which has the authority needed to get the job done (Highsmith, 2009). 'Reflective actions' in the industry-academia context imply that the project team and the steering group will optimise the working methods based on changes and opportunities that arise during the course of the project.

Table 10. The principles from Agile Manifesto that are found to be relevant for IPN projects (*Manifesto for Agile Software Development*, n.d.)

Agile principles from the Agile Manifesto adapted to IPN projects	Shortening of the description of the agile principles for the purpose of the study
The project must handle changing requirements, even in late development	Flexibility
The company must collaborate closely with customers and suppliers	Collaboration
Face-to-face conversation is the best form for communication	Communication
Early, continuous, and frequent delivery of valuable products	Incremental & iterative learning
Management empowers self-organised multi-disciplinary project teams	Enabling environment
At regular intervals, the project team reflects on how to become more effective and adjusts working methods accordingly	Reflective actions

To answer the research questions, we developed a survey asking project leaders about their subjective opinions concerning the importance of agile management practices for innovation success of IPN projects. The survey included the management practices associated with the six agile principles across the three project stages, as shown in *Table 11*, *Table 12*, and *Table 13*. In most cases, two important practices were defined for each agile principle in each project stage. In total, the survey included 38 practices.

Table 11 The management practices related to the agile principles in the project planning stage

Agile Principles	Management Practices
Flexibility	The project team continuously modifies innovation goals based on the knowledge emerged during the project.
	The project planning team includes spin-offs as a possibility for exploitation of the new knowledge.
Collaboration	The university uses the innovation project with industry to build knowledge in a long-term perspective.
	The industry uses the innovation project with universities to build competence in a long-term perspective.
Communication	Researchers from the university can apply and explain theoretical knowledge in an industrial setting.
	The industry employees are open to adopting new knowledge created in the innovation project.
Incremental & iterative learning	The management of the industrial company assesses the value of the project results when the project is completed.
	The management of the industrial company assesses the value of the project results continuously during the project.
Enabling environment	Innovation projects are crucial for the company's future.
	The management of university and industry provides full support and independence to the project team.
	Both the industrial company and the university allocate the necessary resources to the innovation project.
	The company's management approves the work packages and objectives for the project.
	The company's management actively participates in the preparation of the project's work packages and objectives.
Reflective actions	The steering group reflects on how they can work effectively together and adapts their working methods and attitudes accordingly throughout the project.
	Both the industrial company and the university develop their organisations in line with the opportunities that the innovation project generates.

Table 12. The management practices related to the agile principles in the project execution stage

Agile Principles	Management Practices
Flexibility	The project team is working in a strategic direction
	End users are involved in continuous testing of prototypes to find the 'real industrial needs' and to reject 'the constructed' needs.
Collaboration	The technology integrator who is responsible for the implementation of the research results in industry is involved in the project from an early stage.
	Prototypes are built at the industrial company location, so that everyone can contribute.
Communication	Communication is done via face-to-face meetings and through visualisation and prototype building.
	The core team in the project has a common interpretation for the most important knowledge in the project.
Incremental & iterative learning	All departments in the organisation have the opportunity to provide inputs and learn from the project along the way.
	The end user continuously helps to navigate the project's direction.
	The customer continuously helps to navigate the project's direction.
Enabling environment	The project team works independently and organises their own progress.
	The project has a stable core team dedicated to the project.
Reflective actions	The project team reflects on how they can work effectively and adapts their working methods and attitudes accordingly throughout the project.

Table 13. ***The management practices related to the agile principles in the project evaluation stage***

Agile Principles	Management Practices
Flexibility	The needs of industrial companies' customers are built into the prototypes and demonstrators, and will, thus, form the basis for learning during further development.
	Ongoing technology development is considered continuously throughout the project.
Collaboration	The end user is involved throughout the project to ensure that the result integrates the practical knowledge needed to use the product.
	Stakeholders provide frequent feedback and their knowledge is continuously built into the product.
Communication	Demo and prototypes are used to create learning.
	Trust and mutual understanding are the basis for effective communication between stakeholders.
Incremental & iterative learning	Customers of the industrial company evaluate the results and make new contributions to the innovation project at regular intervals during the project period.
	Prototypes are built at the industrial company, so that everyone can continuously provide input throughout the project period.
Enabling environment	Those who are involved in the project have sufficient time for learning, reflection, and knowledge building.
	Typical innovators in the industrial company, who are experts in the application of knowledge, have a central role in the project group.
Reflective actions	The project team continually reflects on how they learn and develop new knowledge, consequently improving their methods throughout the project.

The perceived importance of the defined practices was assessed on a five-point Likert scale, where '1' denotes 'not important' and '5' denotes 'very important'. Before sending the survey to the respondents, it was piloted with three project leaders from industry, university, and research institutions. They confirmed that a five-point Likert scale was suitable (Dawes, 2008; Dinesh Joshi Ankur & Kale, 2015). Additional constructive feedback helped in improving the survey in several aspects. For instance, one of the comments was if the project leaders should base the answers on their general experiences with IPN projects or on a specific project. The pilot indicated that it was better for the respondents to refer to their general IPN project experience rather than that of one specific project, since it was considered beneficial for the study to utilise a broad range of project experience.

The respondents were project leaders for IPN projects, selected based on the following criteria:

- Company operates within the manufacturing industry;
- Project conducted during the time period 2011-2019.

We used Google forms to create a survey. Before sending out the survey link, the respondents were contacted via a phone call to briefly explain the survey and its purpose. The intention was to motivate project leaders to participate in the study and thereby increase the response rate.

The survey was sent to 189 selected project leaders identified from the RCN database (*The Research Council of Norway. Projectbank*, n.d.) and to IPN project leaders that work in the engineering department at a university. The survey was not notified to the Data Protection Services, since the questionnaire did not contain information that could identify individuals directly or indirectly. Moreover, the questionnaire at any point of the process was not connected to identifying information about each respondent such as their IP address or email address (*Norwegian Centre for Research Data*, n.d.). The reminder was sent once to all the respondents. Two weeks after sending out the survey, 124 responses were received.

4.2. Data analysis

We used SPSS statistical software to analyse the data. To get a general overview of what the project leaders think of agile in IPN projects, we first examine the mean values and the related standard deviations (SD). As a rule of thumb, a SD that is closer to one indicates that values are spread out over a wider range (Ringdal, 2018).

For RQ1, we apply a confirmatory factor analysis that identifies factor loadings. A factor loading exceeding 0.4 would indicate adequate correlation between the management practices and the corresponding agile principles (Julie Pallant, 2020).

Next, we evaluate Cronbach's alpha (CA) that indicates the consistency of the entire survey and, thus, evaluates its reliability. CA values above 0.6 are considered acceptable. The higher the CA, the higher the internal consistency (Julie Pallant, 2020).

To test the validity of the correlations between the practices and the agile principles, we evaluate average variance extracted (AVE). An AVE > 0.50 indicates that more than half of the indicator variance is contained within the construct score (Hair et al., 2018). However, following the recommendations of Fornell and Larker, if the AVE is close to 0.4 and the reliability (CA) is higher than 0.6, the validity of the correlations is still adequate and can be accepted (Fornell & Larcker, 1981).

Furthermore, we investigate the existence of discriminant validity to examine consistency between the project stages. Discriminant validity is confirmed if the square root of AVE is higher than the latent variable's correlation with other constructs.

The factor loadings, CA, AVE, and existence of discriminant validity indicate that the management practices correspond well to the agile principles in the three project stages. This indicates an affirmative response for RQ1, justifying the use of the survey to answer the other research questions.

For RQ2, we apply factor analysis to identify correlation coefficients between the agile principles in three project stages. Correlation coefficients above 0.5 are considered to indicate high correlation. Correlation coefficients between 0.3 and 0.49 denote that the variables that are moderately correlated. Correlation coefficients that are less than 0.3 have little, if any, (linear) correlation (Julie Pallant, 2020).

Next, we apply a one-way analysis of variance (t-test) to answer RQ3. The t-test identifies if there is a significant difference in assessing the importance of the agile principles between the project leaders from industry and academia. A *p*-value lower than or equal to 0.05 indicates statistically significant differences between the two groups (Julie Pallant, 2020).

5. RESULTS

Table 14 presents the descriptive statistics, in terms of means and standard deviations, of the responses of 124 project leaders regarding the perceived importance of the application of agile principles for the success of IPN projects.

Table 14. ***Descriptive statistics of the responses of 124 project leaders regarding their perception of the importance of agile principles in the context of each project stage***

	Project Planning Stage		**Project Execution Stage**		**Project Evaluation Stage**	
Agile Principles	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Flexibility	3.89	0.77	4.13	0.59	4.04	0.60
Collaboration	**4.23**	0.73	3.68	0.85	3.83	0.74
Communication	**4.33**	0.58	3.95	0.61	**4.32**	0.57
Incremental & iterative learning	4.12	0.60	**3.55**	0.61	**3.53**	0.74
Enabling environment	3.93	0.55	**4.20**	0.63	3.97	0.63
Reflective actions	**3.77**	0.72	3.94	0.81	3.69	0.88

Note: SD = Standard Deviation

In the project planning stage, the highest average value is predicted for the agile principle 'Communication', closely followed by 'Collaboration'. The agile principle 'Reflective actions' has the lowest mean value. In the project execution stage, the agile principle 'Enabling environment' exhibits the highest mean value, whereas 'Incremental & iterative learning' has the lowest. In the project evaluation stage, the respondents gave the highest score to 'Communication' and the lowest to 'Incremental & iterative learning'.

However, it should be noted that the statistics demonstrate higher standard deviations for some principles, which indicates a wider range of perceptions for these principles (Ringdal, 2018). Notably, the agile principles 'Reflective actions' and 'Collaboration' have the highest standard deviation across all project stages.

5.1. Results underpinning the answer to RQ1

Table 15 presents the results of the factor analysis, which reveals that in the project execution stage, the agile principle, 'Communication' reports low loading (0.368). The loadings for the rest of the agile principles exceed 0.442, indicating sufficient correlation between the management practices and the agile principles within each of the project stages.

Table 15 also reports the results of reliability test, indicating that CA exceeds 0.6 in all project stages, thereby confirming the reliability of the survey.

Furthermore, *Table 15* shows the validity of the study. Calculation of AVE for all stages reveals two numbers slightly lower than 0.4. However, it is believed that the validity of the survey is still adequate since CA is higher than 0.6 (Fornell & Larcker, 1981).

Table 15. ***Factor loadings, CA, and AVE of the survey responses***

Project stages (Construct)	CA	AVE	Agile principles (Indicators)	Loadings
Project Planning	.642	0.382	Flexibility	.713
			Collaboration	.643
			Communication	.622
			Incremental &Iterative Learning	.724
			Enabling environment	.442
			Reflective actions	.512
Project Execution	.66	0.408	Flexibility	.462
			Collaboration	.787
			Communication	***.368***
			Incremental &Iterative Learning	.615
			Enabling environment	.646
			Reflective actions	.643
Project Evaluation	.782	0.359	Flexibility	.643
			Collaboration	.524
			Communication	.553
			Incremental &Iterative Learning	.645
			Enabling environment	.568
			Reflective actions	.649

Note: CA = Cronbach's alpha; AVE = Average variance extracted

Discriminant validity coefficients, using the square root of AVE, are presented in *Table 16*. The square root of AVE is higher than the latent variable's correlation with other project stages, which indicates validity of the connections between the management practices and the corresponding agile principles in the respective project stages.

Table 16. ***Discriminant validity coefficients***

	Project Planning	Project Execution	Project Evaluation
Project Planning	0.618		
Project Execution	0.485	0.639	
Project Evaluation	0.457	0.57	0.599

Overall, therefore, the results show that the management practices are aligned with the agile principles across the three stages of IPN projects.

5.2. Results underpinning the answer to RQ2

The SPSS row data underpinning the answer to RQ2 is presented in *Table 20* in the Appendix. The results have been structured and presented in **Error! Reference source not found.** and **Error! Reference source not found.**.

Fig 13 depicts the agile principles that have strong and medium interconnections between the different project stages.

The execution and evaluation stages have strong correlations with each other through the agile principles 'Flexibility' and 'Reflective actions', and moderate correlations through the principles 'Incremental & iterative learning' and 'Enabling environment'. The planning and execution stages have moderate correlations with each other through the agile principles 'Flexibility', 'Incremental & iterative learning', and 'Reflective actions'. The evaluation and planning stages demonstrate moderate correlation with each other through the agile principle 'Reflective actions'. Thus, 'Reflective actions' is the only principle that reports correlations throughout all the three stages.

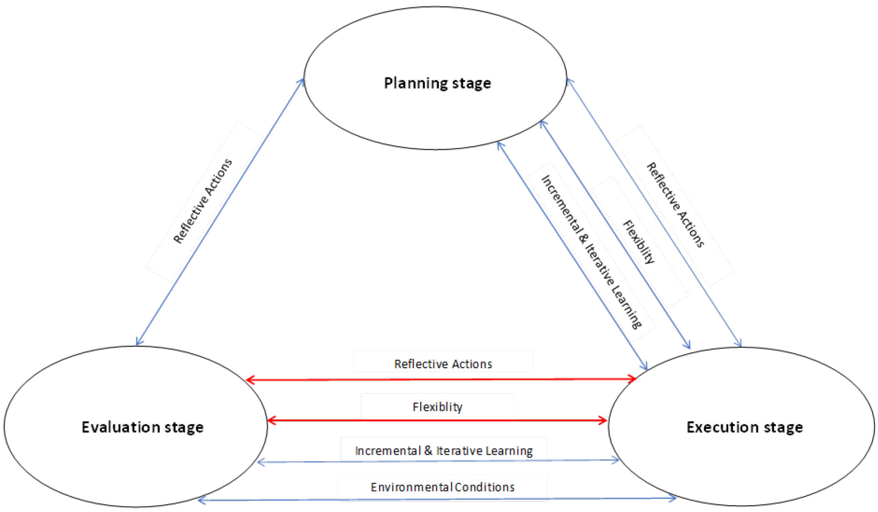

Fig 13. Agile principles showing strong and medium interconnections between different project stages of IPN project

Additionally, factor analysis shows that 'Reflective actions' in the execution stage has the strongest correlations with all the other principles in all stages (*Table 20*).

'Reflective actions' stands out in the cross-correlations analysis of the principles as well, which is shown in Fig 14. Strong connections were found between this principle and 'Enabling environment' in the planning stage as well as between the execution and evaluation stages.

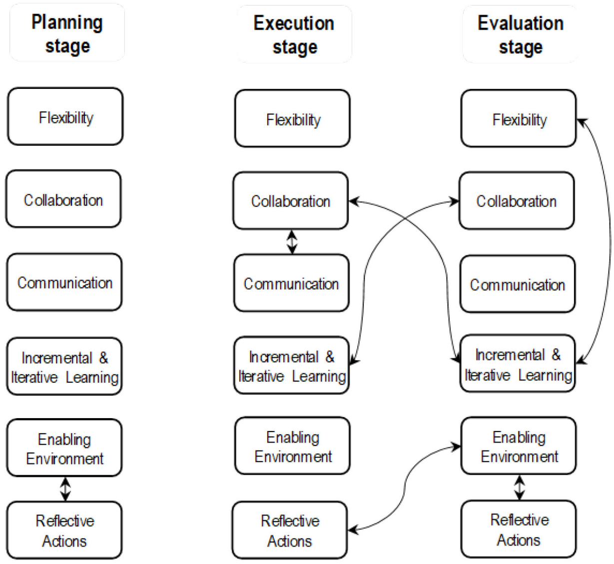

Fig 14. Cross-correlations for the agile principles in the three stages of IPN projects

The lowest correlations among all the stages were identified for ‘Collaboration’. However, in terms of cross-correlations, ‘Collaboration’ is strongly interrelated with ‘Communication’ in the execution stage. Interestingly, cross-correlations between ‘Collaboration’ and ‘Incremental & iterative learning’ were observed between the execution and the evaluation stages. The agile principle ‘Incremental & iterative learning’ also has a strong interrelationship with ‘Flexibility’ in the evaluation stage.

5.3. Results underpinning the answer to RQ3

In the next analysis, the respondents were divided into two categories – industry and academia. The former (70 respondents) included leaders of IPN projects who are employed in the industry domain. The ‘academia’ category (54 respondents) were leaders of IPN projects who were employees in a research institution or university.

The results for the planning stage are shown in *Table 17* and reveal very little significant differences between how project leaders with industrial and academic backgrounds rate the importance of the agile principles. The only statistically significant difference between the two groups is observed for the principle ‘Enabling environment’, with a *p* value of 0.009.

Table 17. T-test: ***Differences between groups of leaders in the project planning stage***

Source	N	Mean	Comparing groups	Mean difference	*p* value
Flexibility	70	3.97	Industry	0.19	0.183
	54	3.78	Academia		
Collaboration	70	4.27	Industry	0.1	0.466
	54	4.18	Academia		
Communication	70	4.26	Industry	-0.19	0.072
	54	4.45	Academia		
Incremental & iterative learning	70	4.17	Industry	0.14	0.234
	54	4.04	Academia		
Enabling environment	70	**4.03**	Industry	0.27	**0.009**
	54	**3.77**	Academia		
Reflective actions	70	3.79	Industry	0.04	0.724
	54	3.75	Academia		

Note: *p* value ≤ 0.05 =significant difference

Table 18 shows the differences between the two groups in the execution stage. The most significant difference is identified for 'Collaboration' with a *p* value of 0.007. The industry group gives this principle higher importance than academia. 'Flexibility' is the other agile principle that shows statistically significant differences between the two groups with a *p* value of 0.04. Both groups assess this principle relatively high on an absolute scale – 4.22 and 4.00 for industry and academia, respectively.

Table 18. ***T-test: Difference between groups of leaders in the project execution stage***

Source	N	Mean	Comparing groups	Mean difference	*p* value
Flexibility	70	**4.22**	Industry	0.22	**0.04**
	54	**4.00**	Academia		
Collaboration	70	**3.85**	Industry	0.42	**0.007**
	54	**3.44**	Academia		
Communication	70	3.95	Industry	-0.02	0.88
	54	3.97	Academia		
Incremental & iterative learning	70	3.61	Industry	0.15	0.2
	54	3.46	Academia		
Enabling environment	70	4.24	Industry	0.08	0.478
	54	4.16	Academia		
Reflective actions	70	3.97	Industry	0.07	0.624
	54	3.90	Academia		

Only one agile principle was found to be perceived differently between the two groups in the project evaluation stage. As given in *Table 19*, the most significant differences were identified for 'Enabling environment', with a *p* value of 0.001. The relative importance of this principle is rated higher by the industry respondents than by those in academia.

Table 19. ***T-test: Difference between groups of leaders in the project evaluation stage***

Source	N	Mean	Comparing groups	Mean difference	*p* value
Flexibility	70	4.10	Industry	0.15	0.178
	54	3.95	Academia		
Collaboration	70	3.93	Industry	0.26	0.054
	54	3.68	Academia		
Communication	70	4.39	Industry	0.16	0.126
	54	4.23	Academia		
Incremental & iterative learning	70	3.57	Industry	0.1	0.45
	54	3.47	Academia		
Enabling environment	70	**4.12**	Industry	0.39	**0.001**
	54	**3.74**	Academia		
Reflective actions	70	3.82	Industry	0.32	0.052
	54	3.5	Academia		

6. DISCUSSION

6.1. RQ1: Are the agile principles aligned with the management practices throughout the IPN project?

The factor analysis, aimed at answering RQ1, identified adequate values of factor loadings for all agile principles, except the principle of 'Communication' in the execution stage. The results of CA, AVE, and discriminant validity coefficients showed significant correspondence between all agile principles and the related management practices across the three project stages. This may compensate for the slightly low factor loading for the principle 'Communication'.

However, it is important to understand project leaders' perception of the 'Communication' principle. This is of particular interest since proper communication is important in collaborative knowledge creation (Krogh et al., 2000; Ikujiro Nonaka et al., 2006).

Innovation combines knowledge embodied in different fields of expertise, and it is well-documented that different organisations, and even different departments within an organisation, have challenges with communication. At the individual level, experts from different knowledge fields frequently have challenges to interact and understand each other (Amabile et al., 2005; Fleming et al., 2007; Galan-Muros & Davey, 2019; Milliken et al., 2003). As a countermeasure, APM focuses on daily face-to-face interactions of businesspeople and developers throughout the project (Highsmith, 2009; *Manifesto for Agile Software Development*, n.d.).

However, an IPN project does not involve such frequent communication. An IPN project is typically 'plan driven' and works towards intermediate and long-term project goals. IPN projects rely on structured project plans with formal objectives, activities, and milestones throughout the project period. Since the project team has scheduled meetings (say every 14th day), communication in the project tends to be more in the form of written reports, and lesser via face-to-face discussions. This might explain why project leaders with experience in structured IPN projects perceive the importance of the 'Communication' principle to be lower than other principles. However, according to KM fundamentals, organisational learning relies on individual knowledge (Chesbrough & Bogers, 2014; Ikujiro Nonaka et al., 2006). Therefore, industry and academia should direct their attention to the application of the 'Communication' principle.

Overall, the results related to RQ1 support the alignment of the agile principles and the management practices in IPN projects. The alignment is also confirmed in all three project stages. Thereby, the results on RQ1 verify the scientific rigor of the survey as a research instrument for collecting data, which, in turn ensures that the results for the research questions are valid and reliable. Next, the identified consistency of the agile principles means that management practices in the survey accurately reflect the corresponding agile principles in three project stages, i.e. the project leaders can trust the categorisation of the management practices in relation to the agile principles in IPN projects. Thus, project leaders can adapt the agile principles as guidelines for improving management practices.

6.2. RQ2 - How do project leaders perceive the importance of the agile principles in different stages of IPN projects?

The findings related to RQ2 show which of the agile principles are perceived as consistent throughout the project stages. The results show that 'Incremental & iterative learning', 'Flexibility', and 'Reflective actions' are perceived as most important for IPN projects. The correlations between the agile principles show that if one of these principles is used in the execution stage, it will be also used in the planning and in the evaluation stages. However, only the use of 'Reflective actions' in the evaluation stage triggers its use in the planning stage.

We will now elaborate on the results in terms of each of these three principles.

Application of the 'Incremental & iterative learning' principle will support IPN projects by the integration of each stakeholder's unique knowledge domain (Kazadi et al., 2016; Laine et al., 2015). Addressing stakeholders' knowledge in the execution stage will trigger examinations in the evaluation stage and adaptions in the planning stage. This feedback loop will help the project team to navigate the project (Schulze et al., 2014). However, the project leaders will not use 'Incremental & iterative learning' between the evaluation and the planning stages. This means that stakeholders' innovative strategy will not benefit from the IPN project since organisational knowledge creation requires transformation of knowledge learned at the project-team level to the organisational level (Ikujiro Nonaka et al., 2000; Ikujiro Nonaka et al., 2006). If the stakeholders do not expand their knowledge base through collaboration, they cannot contribute to IPN projects to the full extent (Cohen & Levinthal, 1990; Zahra & George, 2002).

The 'Flexibility' principle is about exploring, failing, and continuously developing new products or processes to ensure continuous adaptability to changing requirements (Conforto et al., 2014; Yannou, 2013). The results demonstrate how adaptation to the changes made in the execution stage will be assessed in the evaluation stage and will consequently trigger a response in the planning stage. This feedback loop shows that the IPN project will adapt to the changes at the project-team level. However, project leaders will not use the 'Flexibility' principle between the evaluation and the planning stages. This indicates that the continuous changes in customers' needs and technology development will not be taken into consideration by the project (A. B. Sandberg & Crnkovic, 2017). The detachment from the organisational strategies will also not allow for reallocation of the resources based on shifting needs of the IPN project (Lazonick, 2006; West et al., 2014).

'Reflective actions' is the only principle that has strong and moderate correlations between all project stages. The principle is also significantly correlated to all the other principles within the execution stage, indicating the importance of enabling team dialogues, workshops, seminars, as well as informal and formal team platforms to discuss results, experiments, and models. The correlations of the 'Reflective actions' principle demonstrate that project leaders emphasise the importance of inspections and adaptation of the working methods at the level of the project team and the organisation (Derby et al., 2006; Ikujiro Nonaka et al., 2000).

Regarding cross-principle correlations, there are strong correlations between the 'Reflective actions' and 'Enabling environment' principles within the planning and evaluation stages, as well as between the execution and evaluation stages. These correlations emphasise that the management should provide all necessary resources for the project team to work effectively and efficiently. The management should reflect on the changes that occur during the project and make necessary adjustments in the resources needed to run the project. From the knowledge perspective, time is one of the vital resources. Giving the project team enough time to work on a project is a precondition for people's will to invest time in building knowledge with others (Krogh et al., 2000; Lazonick, 2006; Reagans & McEvily, 2003).

The evidence from previous studies show that the projects in which the project team have insufficient time produce lower innovation as compared to the projects where the team gets necessary support from management (Pertuzé et al., 2010).

6.3. RQ 3 – How do project leaders from industry and academia perceive the importance of the agile principles in different stages of IPN projects?

The findings related to RQ3 identify the agile principles that are perceived to be more important by the industry than by academia.

In the planning and evaluation stages, it is the 'Enabling environment' principle. The IPN project and academic career require the academics to make the research public. Therefore, academics dedicate considerable time to work on publications rather than to ensure implementation of research results. Meanwhile, the industry's concern is to facilitate project team work to make the IPN project successful.

‘Flexibility’ in the execution stage is the other principle that is perceived to be more important by the industry than by academia. Industry is the owner of the project and must deal with any challenges that arise during development process. Thus, integrating flexibility into the IPN project is a major concern for industry (Durney & Donnelly, 2015; Marchesi et al., 2007).

‘Collaboration’ in the execution stage is another principle that is perceived as being more important by the industry than by academia. Industry is in charge of organising and facilitating the collaboration between the stakeholders on one side and the project team on the other (Kazadi et al., 2016; Rigby et al., 2016a). The principle supports development of their own language and norms, thereby fostering a ‘community of innovation’ with its inherent socialisation context (Foss et al., 2011; Ikujiro Nonaka et al., 2000). The context provides for trust and mutual understanding that are vital for collaborative knowledge creation and learning processes (Jacob et al., 2000; Laine et al., 2015). In this manner, the principle ‘Reflective actions’ helps industry and academia to build similar knowledge bases and knowledge assimilation processes. The similarity is necessary to leverage knowledge learned from collaborative projects and to build long-term partnerships in research and innovation (Carayannis et al., 2000; Cohen & Levinthal, 1990).

7. CONCLUSION

The objective for this study was to investigate the potential of the agile principles in supporting project leaders in management of industry-academia research and innovation projects. In the presence of such potential, we explored how the agile principles should be applied in different project stages.

To achieve the research objectives, we surveyed 124 IPN project leaders (70 from industry; 54 from academia) in Norway, to evaluate the importance of the management practices associated with the six agile principles across the three stages of IPN projects.

Regarding RQ1, the statistical analyses indicate the alignment of the agile principles and the management practices throughout the project stages. Thereby, the results verify the scientific rigor of the survey as a research instrument for collecting data, which, in turn ensures that the results for the research questions are valid and reliable (Pallant, 2020). Next, the identified consistency of the agile principles throughout the three project stages means that management practices in the survey accurately reflect the corresponding agile principles in three project stages. This means that agile principles are relevant for IPN projects and can be used as guidelines for improving knowledge management practices.

With respect to RQ2, the study identifies the agile principles ‘Reflective actions’, ‘Incremental & iterative learning’, and ‘Flexibility’ as perceived to be the most important in IPN project. These findings can support project leaders implementing the agile principles to industry-academia research and innovation projects.

Nevertheless, the identified importance of the agile principles also highlights the critical aspects related to knowledge management in IPN projects. The study shows that ‘Reflective actions’ is the only principle that supports knowledge creation and learning processes throughout the three project stages. The finding emphasises the importance of improving the collaborative working methods both on the project level and strategic organisational levels. Meanwhile, 'Incremental and iterative learning' and 'Flexibility' principles are perceived to be important to follow on the project-team level, but not on the strategic level. From the organizational knowledge creation perspective, following 'Incremental and iterative learning' would entail transformation of new knowledge learned on the project level to the strategic level (Ikujiro Nonaka et al., 2006). In this way, industry, academia, and other stakeholders would be able to integrate new knowledge from the IPN project in their innovation strategies. The absence of such potential means lost opportunity for partners to increase innovative capability and contribute to the growth of a knowledge-based society (Carayannis & Campbell, 2020; Lundvall, 2012). Additionally, not following the 'Flexibility' principle on the strategic level implies that the continuous changes in customers' needs and technology development will not be taken into consideration by the project. This can lead to the situation when there will be no need for innovation that was required before changes. Consequently, the innovation will fail (Rigby et al., 2016a).

The results for RQ3 revealed some differences in how project leaders from industry and academia perceive the importance of the agile principles in different stages of IPN projects. Unlike the academics, the industry perceives several agile principles to be more important, particularly 'Enabling environment' in the planning and evaluation stages, and 'Flexibility' and 'Collaboration' in the execution stage.

Awareness of these different perceptions of the importance of different agile principles should be taken into consideration when implementing agile principles in IPN projects.

The results from the study can also support national and federal research/innovation councils in decision-making when assessing industrial research applications.

Overall, the study indicates the potential of applying agile principles for improving management practices in industry-academia research and innovation projects. This implies that agile principles can potentially become a management tool for supporting industrialisation of research results, thereby bridging the *valley of death* in such projects. Therefore, this study calls for further research on purposeful application of agile principles for refining management practices in industry-academia research and innovation projects.

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APPENDIX

Table 20. ***Factor analysis: correlation between agile principles in different project stages***

Variables	Flex Pla	Flex Ex	Flex Ev	Coll Pla	Coll Ex	Coll Ev	Comm Pla	Comm Ex	Comm Ev	I&I.L. Pla	I&I.L. Ex	I&I.L. Ev	Enab.Env. Pla	Enab.Env. Ex	Enab.Env. Ev	Refl.Act. Pla	Refl.Act. Ex	Refl.Act. Ev
Flex Pla	**1**	**0,370**	**0,189**	**0,224**	**0,358**	**0,257**	0,087	**0,336**	0,018	**0,365**	**0,279**	**0,193**	0,161	0,120	0,151	0,129	**0,298**	0,160
Flex Ex	**0,370**	**1**	**0,520**	0,137	**0,419**	**0,346**	**0,235**	**0,347**	**0,352**	**0,231**	**0,412**	**0,361**	**0,262**	**0,212**	**0,220**	**0,295**	**0,341**	**0,271**
Flex Ev	**0,189**	**0,520**	**1**	0,043	**0,369**	**0,349**	0,105	**0,262**	**0,454**	**0,188**	**0,326**	**0,533**	**0,241**	**0,246**	**0,419**	**0,306**	**0,385**	**0,391**
Coll Pla	**0,224**	0,137	0,043	**1**	0,124	0,148	**0,288**	**0,220**	0,084	0,054	0,100	0,120	**0,221**	**0,279**	**0,238**	**0,265**	**0,355**	**0,365**
Coll Ex	**0,358**	**0,419**	**0,369**	0,124	**1**	**0,238**	0,137	**0,637**	**0,346**	0,124	**0,238**	**0,575**	**0,203**	**0,203**	**0,192**	0,151	**0,366**	**0,243**
Coll Ev	**0,257**	**0,346**	**0,349**	0,148	**0,238**	**1**	0,022	**0,208**	**0,189**	**0,213**	**0,522**	**0,452**	**0,274**	0,036	**0,258**	**0,227**	**0,259**	**0,257**
Comm Pla	0,087	**0,235**	0,105	**0,288**	0,137	0,022	**1**	**0,228**	**0,204**	0,174	0,133	0,058	**0,185**	**0,321**	**0,243**	**0,220**	**0,292**	**0,200**
Comm Ex	**0,336**	**0,347**	**0,262**	**0,220**	**0,637**	**0,208**	**0,228**	**1**	**0,254**	0,089	**0,326**	**0,295**	**0,258**	**0,267**	**0,256**	0,153	**0,341**	**0,178**
Comm Ev	0,018	**0,352**	**0,454**	0,084	**0,346**	**0,189**	**0,204**	**0,254**	**1**	0,130	**0,234**	**0,353**	**0,269**	**0,257**	**0,385**	**0,330**	**0,383**	**0,436**
I&I.L. Pla	**0,365**	**0,231**	**0,188**	0,054	0,124	**0,213**	0,174	0,089	0,130	**1**	**0,321**	**0,293**	**0,387**	0,023	0,125	**0,274**	**0,202**	0,108
I&I.L. Ex	**0,279**	**0,412**	**0,326**	0,100	**0,238**	**0,522**	0,133	**0,326**	**0,234**	**0,321**	**1**	**0,437**	**0,400**	**0,188**	**0,399**	**0,296**	**0,319**	**0,284**
I&I.L. Ev	**0,193**	**0,361**	**0,533**	0,120	**0,575**	**0,452**	0,058	**0,295**	**0,353**	**0,293**	**0,437**	**1**	**0,214**	**0,206**	**0,362**	**0,228**	**0,316**	**0,335**
Enab.Env. Pla	0,161	**0,262**	**0,241**	**0,221**	**0,203**	**0,274**	**0,185**	**0,258**	**0,269**	**0,387**	**0,400**	**0,214**	**1**	0,175	**0,276**	**0,531**	**0,335**	**0,354**
Enab.Env. Ex	0,120	**0,212**	**0,246**	**0,279**	**0,203**	0,036	**0,321**	**0,267**	**0,257**	0,023	**0,188**	**0,206**	0,175	**1**	**0,354**	**0,196**	**0,353**	**0,320**
Enab.Env. Ev	0,151	**0,220**	**0,419**	**0,238**	**0,192**	**0,258**	**0,243**	**0,256**	**0,385**	0,125	**0,399**	**0,362**	**0,276**	**0,354**	**1**	**0,330**	**0,512**	**0,613**
Refl.Act. Pla	0,129	**0,295**	**0,306**	**0,265**	0,151	**0,227**	**0,220**	0,153	**0,330**	**0,274**	**0,296**	**0,228**	**0,531**	**0,196**	**0,330**	**1**	**0,485**	**0,457**
Refl.Act. Ex	**0,298**	**0,341**	**0,385**	**0,355**	**0,366**	**0,259**	**0,292**	**0,341**	**0,383**	**0,202**	**0,319**	**0,316**	**0,335**	**0,353**	**0,512**	**0,485**	**1**	**0,570**
Refl.Act. Ev	0,160	**0,271**	**0,391**	**0,365**	**0,243**	**0,257**	**0,200**	**0,178**	**0,436**	0,108	**0,284**	**0,335**	**0,354**	**0,320**	**0,613**	**0,457**	**0,570**	**1**
Values in bold are different from 0 with a significance level alpha=0,05																		
	4,696379	6,331192	6,324448	4,265311	5,924576	5,255299	4,132701	5,655196	5,678404	4,301904	6,215314	6,329729	5,745687	4,753575	6,333703	5,870629	7,113	6,543453

Appendix II: Supportive Papers

SUPPORTIVE PAPER 1

TOWARDS A FRAMEWORK FOR MANAGING KNOWLEDGE INTEGRATION IN UNIVERSITY-INDUSTRY COLLABORATION PROJECTS.

Hansen, I.-E. (main author), Mork, O. J., & Welo, T.

Proceedings of the European Conference on Knowledge Management, ECKM (2018)

Abstract. Previous studies have called for more research on knowledge management in collaborative projects between university and industry. The scientific community urges the development of managerial mechanisms that will stimulate innovation outcomes and make government-funded projects to generate more long-term value for the society. This study is intended to contribute to close this gap through development of a practical framework for management of university-industry collaboration with knowledge transformation in focus. It concentrates on how to manage the innovation process by leveraging creation, accumulation, dissemination, application, storing, and retrieving of knowledge in university-industry innovation projects. The context for this investigation was a Norwegian region with a local university campus and local maritime/marine companies, mostly concerned with mechanical engineering. Ten in-depth interviews with CEO's, project managers and researches experienced in such projects were undertaken. The questions covered different topics, including project strategy, objectives, facilitation and accumulation of knowledge. The study reviewed knowledge management models in the literature, and found Wallin and Von Krogh's five-step model for the integration of knowledge in open innovation setting suitable for the university-industry context chosen. The results propose a conceptual process model of knowledge management in university-industry innovation projects, which addresses the initiation of specific strategic efforts on organisational, collaborative and project levels. These efforts are intended to ensure the partners' commitment to the project, which in turn enables and leverages knowledge co-creation and exploitation. The findings provide the potential to contribute to more effective and efficient management of the innovation processes between industry and university and reinforce a knowledge-based society. The sample size will be extended be more interviews to extend the data basis in the future.

Keywords: knowledge management, university-industry collaboration, innovation

1. INTRODUCTION

The concept "open innovation" (OI), introduced by Henry Chesbrough (H. Chesbrough, 2003), targets co-creation of new knowledge through partnership between organisations and individuals. The cooperation on innovation with universities has became an increasingly important part of development for many companies. The basic differences between academic and industrial pose a number of barriers in performing collaborative research projects in the most efficient way. The differences in motivation for collaboration, uniqueness of mind-sets, different professional languages and working routines are just some of the obstacles in obtaining effective knowledge co-creation between industries and universities. The scientific community urges development of managerial mechanisms that will stimulate innovation outcomes and will make government funded projects more sustainable, thus generating more value for society (Sjoer et al., 2016).

The research into university-industry collaboration (UIC) has so far concentrated mostly on the projects inputs—such as motivation to collaborate—and projects outputs—such as numbers of patents and articles published. Since the work product of any innovation project is exploitation of new knowledge and co-creation, either at team or business level, the research focus should be turned to learning and knowledge creation processes (Perkmann et al., 2013).

We took on the challenge to identify knowledge management mechanisms required to conduct the UIC in innovation projects in a way that enables new knowledge creation and exploration of the innovation potential of collaboration. To achieve the research objective, we seek to answer research questions associated with the most challenging areas of UIC; i.e., earlier identified ones related to definition of a long-term strategy and the project objectives, facilitation of projects and exploitation of knowledge (I E Hansen et al., 2017).

A variety of Norwegian industrial companies, working together with universities on innovation, was selected for the investigation. To understand the situation, we started with a small number of responders, counting ten in-depth interviews with industrial project managers including CEOs, academic project managers, and PhDs employed it the company and at the university.

We searched for a model for knowledge integration in innovation projects in the innovation and knowledge management literature. We found many similarities between the local university-industry (UI) context and the five-step model for the integration of knowledge in open innovation due to Wallin and Von Krogh. This model, together with the results from our interviews, supported us in developing a conceptual process model of knowledge management in UI innovation projects, which will be presented in the forthcoming. The model embodies answers to the outlined above research questions and depicts our findings, which include the strategic efforts initiated on three levels: organisational, collaborative and project. Applying the model is intended to leverage the processes of knowledge co-creation and usage, depending on the level of commitment to innovation in both the university and industrial company. The presented model is a truly dynamic and interrelated system model as all of its elements impact on each other. We believe that our proposed framework can serve as practical guideline to assist knowledge managers to conduct UIC research projects more effectively, thus better exploiting knowledge gained from innovation efforts.

2. RESEARCH SCOPE

The investigation is limited to selected companies located on the west coast of Norway, around Aalesund, and to the campus of the Norwegian University of Science and Technology. The geographical constraint was necessary as each setting is unique for each particular industry and university, thus the study requires a systematic evidence-based approach (Galan-Muros & Davey, 2019). In addition, both geographical and technological proximity are keys for open innovation (W. Vanhaverbeke et al., 2014). The marine and maritime industries are prevalent in this region, including shipbuilding companies, fish farms, fish factories, and a multitude of technology suppliers to these businesses. Traditional mechanical engineering and production defines the described technological landscape, which forms the terms for the criteria for the type of projects considered in this study.

As a result of the above, (typically) 3-year long projects owned by the industry, so called 'innovation projects for the industrial sector' are the subject for this research. This type of project that are partially funded by the Research Council (*Research Council of Norway*, 2018), and implies applied, industrial-driven research on technology level, involving universities as research suppliers. The duration of such projects is quite optimal for the purpose of the study because it is sufficiently long for the responders to make inferences. The economic side of the commercialising knowledge through innovations has not been considered, this the focus is only places on the knowledge perspective.

3. RESEARCH METHOD

The scientific environment emphasises the need to apply a qualitative study to understand the processes of knowledge integration in these types of projects (Perkmann et al., 2013). As the people perform knowledge processes, the human dimension is always integrated into any project (Salter et al., 2014) (Polanyi, 1958) (Polanyi, 1966). Thus, the individual experiences of those involved in the projects are essential for our research, meaning that interviewing was considered to be the most appropriate method of collecting data (Yin, 2015). We conducted 10 interviews with managers for research projects: three on behave of industrial companies and three from the university. The other interviewees were PhDs employed either in the companies or at the university, including two industrial PhDs and two traditional academic PhDs. The interviews were done in a semi-structured way and concentrated on the main collaborative issues highlighted by previous studies (I E Hansen et al., 2017):

- How to define a strategy for long-term collaboration between industry and university;
- How to define outcome objectives, so that they meet both industrial and academic demands;
- How to facilitate innovation projects to enable (more) knowledge co-creation;
- How to better integrate, build-on, store and retrieve knowledge in projects.

The interviews lasted between 1–3 hours. Most of the interviews were recorded and transcribed, and notes were taken for the rest. The interviewees approved the analysed interview contents before further data conversion and use.

4. MODIFICATION OF THE KNOWLEDGE INTEGRATION MODEL FOR UNIVERSITY-INDUSTRY CONTEXT

Our investigation in the selected regional context reveals several correlations with the model of knowledge integration in open innovation proposed by Walling and Von Krogh (W&VK). Figure 1 shows their model, which aims to help managers organize open innovation projects with focus on knowledge processes. The model consists of five steps: (1) defining the innovation process steps; (2) identification of innovation-relevant knowledge outside the company; (3) selecting of an appropriate integration mechanism that implies regulations for how internal and external resources will contribute to innovation; (4) creating effective governance mechanisms to regulate the involvement of the outside partners; (5) balancing incentives and controls to manage the contribution of the external partners (Wallin and Von Krogh, 2010).

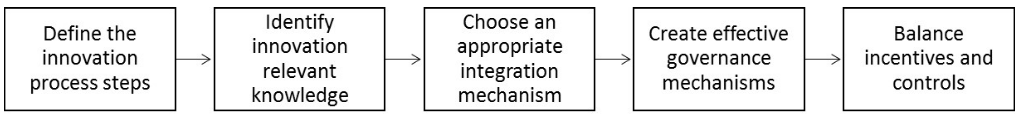

Figure 1: Knowledge integration model (Wallin & Von Krogh, 2010)

Although the analyses of the interviews from our study have strong correlation with the W&VK model, the local university-industry context required some modification of this model to make it more representative. The overall result in terms of a proposition of a conceptual model of knowledge management in UI innovation projects is shown in Figure 2.

The first two phases of defining the innovation process steps and identifying the innovation relevant knowledge in W&VK model correlate with *establishment of long-term collaboration platform* on the strategic collaborative level in our model. The following three phases in W&VK model: choice of appropriate knowledge integration mechanisms, creating the governance mechanisms and balancing incentives and controls are, in a certain degree, integrated in all levels of our model. In the continuation, we will further elaborate on the proposed conceptual model of knowledge management in UI innovation projects.

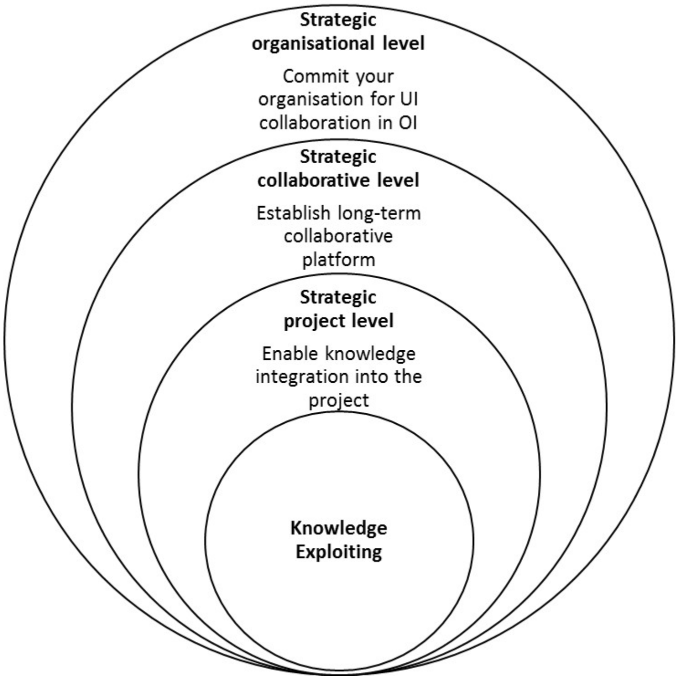

Figure 2: Conceptual model of knowledge management in university-industry innovation projects

5. CONCEPTUAL MODEL OF KNOWLEDGE MANAGEMENT IN UNIVERSITY-INDUSTRY INNOVATION PROJECTS

The proposed model defines that strategic efforts should be applied on the three levels: organisational, collaborative and project. All the efforts influence knowledge exploiting which is the continuing outcome of UI collaboration.

In the UI setting, we found that organisations should be ready to welcome external collaboration by starting within their organisations first. The outer 'strategic organisational level' in Figure 2 reflects this concern. Both the company and the university should regulate incentives and controls internally by strategically allocating and managing resources for organisational learning and for knowledge co-creation. The university and industry should create a strategy on organisational level, which aims to align each partner to committing resources for UIC in open innovation as a first step.

The second step, referred to as 'strategic collaboration level' in **Error! Reference source not found.**, defines a strategy for cooperation that aims to establish a long-term collaborative platform between university and industry. Here it is important to identify common interests and establish procedures that create trust and commitment across both organisations.

On the third level, which is at strategic project level, we discovered a number of strategic decisions that knowledge management should consider to achieve successful outcomes. Such strategic efforts on all levels facilitate innovation by supporting, empowering, and improving quality of knowledge processes.

We propose to present the model by a multi-layered cycle diagram rather than a process diagram, where one-step follows the other in order to highlight that, once established, the described strategic efforts function simultaneously. The model is dynamic in the sense that it supports continued improvements of knowledge management mechanisms on each level, and the interactions and interrelations between levels.

Hence, we accentuate that the innovation outcome from the project between industry and the university is not only the new knowledge created at the end of the project in a form of a new product or processes, but the knowledge that is constantly created and exploited during the entire project, which enable the UI environment to more effectively solve future knowledge-base innovation problems.

We will elaborate further on the model and its elements below.

5.1 Strategic organisational level: commit your organisation for university-industry collaboration in open innovation

The vital precondition for success of UI innovation projects is commitment of both partners to collaboration. This investigation shows that both industrial partners and university should take a strategic decision to commit resources required for strategic competence building. This implies not only the economic investments, but also the allocation and dedication of skills and efforts of employees in the organisational learning process (Lazonick, 2005)(B. Lundvall, 2007).

Furthermore, having knowledge resources available and committed, the organisation should design a management system that effectively and efficiently facilitate these resources in learning and innovation processes. As innovation efforts typically involve utilising resources within the organisation, as well as partners outside organisational boundaries, the innovation management system must (1) encompass organisational culture both towards internal competence building and (2) dedicate resources to ongoing knowledge creating processes with external partners. Below, we provide evidence from responders that confirms the importance of these two aspects of strategic commitment and how this organisational strategy correlates with exploiting new knowledge.

5.1.1 Organisational culture geared towards competence building

Organisational culture determines the willingness and conditions for knowledge sharing in the organisation. The knowledge management literature identifies several aspects related to organisational culture and learning. All of them aim to stimulate and support employees in individual and collective knowledge building (Crossan, 1996). 'Clarity of knowledge-building visions and goals' was one of the culturally associated aspects that were emphasised by our interviewees.

When organisational visions and goals clearly communicate the importance of competence building, the collective ambition is geared towards it. For instance, one of the companies in this study had deliberately chosen not to move production to low-cost countries in order to prevent "drain away" company's knowledge. The technology knowledge is considered a significant competitive advantage, and the company started strategic investments in competence building. This was the main reason for this company to become actively involved in collaborative research projects with universities. The company's research-oriented culture also fosters employees who have ambitions to take a PhD degree. According to the CEO, 'it is important to cooperate with them by giving them tasks they want to work on, in areas where company needs a solution or a study.'

The university in this study has well-defined strategic knowledge-based visions and goals. However, our study reveals that some of university's performance measurements are related to the number and size of projects with the industry; externally financed project funds. This performance indicator can force the university to get involved into many projects and it can turn collaboration into a 'money chase.' As one university project manager states: '…academia should not work for money, but work for knowledge building. If you have a money-thinking attitude, all projects are completed at speed. There is no learning in it.'

The interviewees also stressed the other cultural attribute: 'openness of company attitudes, structure and processes'. This aspect promotes sharing of knowledge across the company. According to one industrial manager, a company's culture affects acquirement, dissemination and accumulation of knowledge. He stated that 'It is very important that knowledge is shared across the company. The role of the project leader is to disseminate knowledge and to be sure that people grasp it. Repeat (knowledge) one, two, three times until people get it.'

The study reveals that university system does not properly foster innovation in the way the need are present in real-world projects. According to responders, undertaking research projects with industry implies solving multidisciplinary problems, involving academic expertise from different university departments. The university's "silo"-structure hampers such a collaborative problem-solving structure. Our study shows that people in academia are not always aware of, or willing to use, the competence available in other departments. There are limited meeting arenas and possibilities for academics to know in which areas their co-academics are experts. This makes internal collaboration harder.

5.1.2 Dedication of resources

If the organisation has none or limited resources to support ongoing communication with a partner, this inhibits project development and propagates negative reputation of the organisation (Lüttgens et al., 2014). This study indicates that the university and industry often underestimate the efforts required for successfully executing collaborative activities. One project manager connects a collaborative project's failure with too low involvement of the company. The reason is rooted in the company's mind-set, which considers research and development activities as something supplemental to, or even outside, the main business. This manager stated that 'the company considers it (research) as variable that is just an expense, not an investment in the future.' This is diametrically opposite to the company mentioned above, which has a strategic approach to 'participate actively in a UI project to get the needed knowledge.' According to the company's CEO, they knowingly approach collaboration with university by 'dedicating resources to closely follow industrial and academic PhDs. This is one of the solutions that allows exploiting collaboration with academia.'

The time commitment required for collaborative projects is also the essential resource that the management of the company and the university must consider. The study illustrates that short time problems always outperform long-term needs. The responders affirm that time-pressure is often a barrier for knowledge building activities. Therefore, it is a management task to strike the right balance between short-term work needs and allocation of time for workers for their knowledge-building activities.

The significance of having time available for exploiting knowledge acquired from a project can be underlined by an academic project manager, who stated: 'It is very important that you (researcher) take your time…It (knowledge) must be externalised… Those who generated an idea must have time to finish thinking and writing.'

5.2 Strategic collaboration level: establish long-term collaborative platform

Building of a knowledge-based society requires alignment of strategies of all stakeholders within the national and regional ecosystems. One CEO in this study said the following: 'The national strategic requirements should align the projects to the research areas significant for the country and the region.'

Both industry and academics say that it is important to find a partner with relevant knowledge for collaboration in innovation. A responder stated that his company undertook collaboration with universities strategically. The company decided to work in a more deliberate way with only carefully selected universities and to invest in innovation projects with them in areas 'that are of core competence for the enterprise.'

Our research demonstrates that those organisations that are aware of the innovation potential from the UI innovation projects, have learned how to work together through experience. According to a CEO: 'Collaboration with academia is a game one should learn to practice in a good way, because there is a great potential of knowledge, knowledge building and competence.' An academic project manager confirms that a long-term relationship has a positive impact on the understanding of each other's needs. She says that if industry has experience, 'they are much more flexible and open to understanding that research is demanding and they cannot always get immediate results...'

Many of responders underline the importance of involving academia seniors, who 'have experience and are used to be industry-involved.' To have a person from academia who 'has the ability to understand the problem, speaks industrial language' helps establishing trust in collaboration project. Simultaneously, to have a person from industrial side who understands the academic word helps establishing mutual trust and common understanding.

5.3 Strategic project level: enabling knowledge integration into the project

The literature on innovation emphasises the need to enrich understanding on how open innovation works on project level in different contexts. Some of the research gaps in this area are the management tools facilitating knowledge co-creation (W. Vanhaverbeke et al., 2014). Our study indicates several major management rules and procedures that we further describe.

5.3.1 Anchoring project at the industry's management

If a research project is not anchored in a company's management, such a project is likely to fail. An academic project manager supports this by stating: 'It (project) must be anchored in the company's headship…otherwise the entire responsibility for the project will be pulverised.' The interviewee means that it is not enough to sign the contract, the managers must feel ownership: 'Management must take responsibility at the start of the project. It is a prerequisite for something (innovation) to happen.' Several industrial representatives support this opinion. One CEO states that the UI projects must be anchored both in company's strategy and in its headship: 'No project should start without management taking a decision to go for it.'

5.3.2 Formulating project objectives and establishing common language

The formulation of project objectives is relevant to both academic and industry intentions. Alignment of the research objectives with the company's strategic core knowledge areas is one of the solutions for this concern. According to one industry manager: 'The theoretical solution should provide serious value for the company…It helps them commit to the project and dedicate enough resources to carry out the entire project to the final implementation phase.' One of the academics insists that the project is 'not on the priority list for the company unless it is going to deliver something … strategically very important to them.'

It is vital that the industry is involved in defining tasks in research application—this is also the intended basis for this type of Research Council funded projects. Due to lack of time and experience in writing research applications in the industry, it is common that the researchers take on this job. As one CEO states 'the company has to be involved in the entire research process starting from the definition of tasks in research application…Otherwise it risks ending up with tasks that are interesting, but not very essential (for the company).'

An industry project manager stats that 'Research purpose must be presented in the business language' is another crucial moment. An academic fully support this opinion: 'When defining goals, one must speak the industry language. It is what creates the big problems when people talk as if from different planets.'

'Common language is a prerequisite for successful collaboration' during the entire project. All of the interviewees emphasised the importance of this; e.g. one interviewee states: 'A common language breaks boundaries.' Arranging common meeting arenas, workshops, use of visualisation tools such as presentations, prototypes, drawings, all help 'to look at a problem and have a common understanding.'

5.3.3 Clarification of expectations and roles

Clarification of both partners' expectations from the research project is a prerequisite for a successful collaboration. The objectives must have a very clear delivery form for knowledge, agreed verification procedure and time perspective.

According to one of the academics: 'it is important that industry gives a little room for research, but it is industry that defines the direction.' A CEO agrees that the industry should follow the project closely, adjusting the tasks according to the desired outcomes because 'such attitude allows utilising knowledge from the project and building competence the company needs.'

The experts with knowledge related to the project should participate from the very first meeting. It involves people from different departments from both university and industry. It is also important to involve the company's customers and suppliers: 'They all should be "on-board" before the project starts to verify the strong need for research... to see it has a significant value…for the industry.'

5.4 Knowledge Exploiting

One of the responders defined: 'Knowledge without application has no meaning.' Even if the collaborative project results in new knowledge and innovation, it is not necessary that the organizations will exploit it (H. W. Chesbrough & Crowther, 2006). Our study shows that partners should not wait to the final research result, but should exploit knowledge throughout the project. Regular communications, presentations, workshops, building of prototypes allow the partners to exchange, co-create and integrate knowledge in both organizations.

As one CEO stated: 'The company has to be in dialog (with PhDs) to get the knowledge. It does not need to be the final report or an article. One can transfer competence orally, in dialog during the project.'

This research demonstrated the importance of involving those who will use the new knowledge. It can be, for instance, operators in the company, which will produce the developed technology or an outside customer. When they contribute to innovation, it makes them feel more ownership to new knowledge and willingness to exploit it.

Utilizing an industrial PhD program is the other beneficial way of exploiting knowledge in industry. According to the contract, the industrial PhDs have to stay with the company for the following 3-4 years after project completion. This secures accumulation and dissemination of knowledge from the projects across the company as well as further development and implementation of project research results.

Exploiting of knowledge in the university ensues transfer of knowledge from the projects to teaching programs and to other current or future innovation projects. According to academic project manager: ‘It (knowledge) must be externalised, you (researcher) need to connect with others and build it into teaching as well as into your next project.’ Dissemination of knowledge also happens through students who participate in projects, where the new knowledge is generated.

Furthermore, the knowledge management tools are being developed within each project. The described structural conditions that support knowledge processes on the strategic organizational, collaborative and project levels are continually improving. It implies that practical guidelines can be developed which can assist knowledge managers to conduct UIC projects more effectively, thus better exploiting knowledge from innovation projects.

6. DISCUSSION AND CONCLUSION

We have studied UI collaboration in innovation projects in a Norwegian context in order to identify factors relevant to knowledge management mechanisms required to conduct the projects in a way that enables new knowledge creation and fully exploits the innovation potential of collaboration. We identified such knowledge management mechanisms answering research questions related to facilitating of projects, defining a strategy for collaboration, making project objectives, and knowledge accumulation.

The study reveals that the university and industrial company involved should concentrate their strategic efforts on the organisational, collaborative and project levels. The strategic efforts imply making knowledge management rules and procedures that enable better exploiting of knowledge gained from innovation project.

Based on the above, we formed our findings into a conceptual process model of knowledge management in university-industry innovation projects. The model is formed as a multi-layered cycle where three layers represent the strategic efforts on the corresponding levels. The fourth level embodies the project outcome: knowledge exploiting. This order of layers is based on our findings that strategies of each individual organisation create the foundation for a joint collaboration strategy, which, in turn, supports the strategy on project level. Together they enable knowledge exploiting. The study outlines that project outcome is not only new knowledge created at the end of the project, but the knowledge that is constantly created and exploited during the entire project.

The model is formed as a multi-layered circle rather than a turn-based process: all of its element impact on each other making it an interrelated system model.

The model is based on the literature study and a limited-size sample of interviews. To verify the model, we will conduct a survey on a larger sample of interviewees.

We believe that our proposed framework can serve as practical guideline to assist knowledge managers to conduct UIC research projects more effectively and make it easier for industry and university to work together in delivering innovation.

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SUPPORTIVE PAPER 2

EXPLORING FRAMEWORK FOR UNIVERSITY-INDUSTRY INNOVATION PROJECTS: BUILDING COLLABORATIVE KNOWLEDGE PLATFORM.

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Abstract. University-industry innovation projects has potential for improvement, especially for bringing new knowledge and technology into new commercial products and processes. This research work explores how a novel knowledge management model made for university industry innovation projects can support universities and industrial companies, project managers and knowledge workers, to help improve the innovation outcome from such projects.

The research method is exploration of the model in the context of a university industry innovation project, focusing the knowledge processes in a pre-project stage, the main project stage and the after project stage. The knowledge management processes in the different stages of the project are documented with project applications for funding, project meetings, project reports, master and PhD thesis work, eight scientific publications and two prototypes. The findings show that the knowledge management model contribute to 1) building of the collaborative long-term knowledge platform 2) keeping focus on the knowledge management initiatives that are preconditions for successful project outcome 3) integration of real industrial needs and the knowledge of the industrial end user, which is decisive for the innovation 4) methodological application of the model to the innovation projects can support sustainable building of the university-industry collaborative knowledge platform. The article elaborates on the performance of the knowledge management model during different project stages: its strengths and weaknesses, as well as development directions and opportunities. The lessons learnt suggest that methodical application of the knowledge management model will be the main driver for further development.

The research work done in this article is a first scientific approach towards a framework for application of this knowledge management model. The next step will be application of the proposed framework to a larger number of university industry projects. This work will be done in cooperation with universities, industrial companies and governmental funding Institutions.

Keywords: university-industry collaboration, innovation projects, knowledge management

1. INTRODUCTION

The article concerns the technological gap, the so called ‘valley of death’, when university-industry (UI) innovation projects fail to make use of research results derived from a project realized in an industrial setting (Maughan et al., 2013a). Application of new knowledge is a prerogative for innovation and therefore it should be a focus in innovation projects (H. W. Chesbrough et al., 2014).

A comprehensive review of studies on cooperation between university and industry presents a conceptual process framework for UI collaboration (UIC). The framework defines the main elements, which influence the results of collaboration. Those are the ways of entering partnership, organizational forms for collaboration, and operational activities that facilitate UI collaboration (Ankrah & AL-Tabbaa, 2015). This systematic review emphasizes that the majority of studies on UIC concentrate on inputs and outputs from the collaboration and its correlations. However, little is done to study 'how' to facilitate UI partnerships to enhance knowledge processes and provide more innovation. In view of this, the research community calls for research on knowledge management (KM) tools that will support knowledge exploration and exploitation in UI collaboration projects (Perkmann & Walsh, 2007)(Perkmann et al., 2013) (I E Hansen et al., 2017).

This article addresses the potential for the novel knowledge management model to support university and industry in delivering even more innovation and building collaborative knowledge platforms in the long term (I.-E. Hansen et al., 2018). The model is based on the organizational knowledge creation model introduced by Nonaka, but extended for the university-industry collaboration in innovation (Ikujiro Nonaka, 1994)(Crossan, 1996). The model pinpoints the knowledge management activities that are prerogative for the success of an innovation project.

This study is based on a three-year project and its six-month pre-project. The project was initiated and owned by the company where it took place, and partly subsided by the Research Council. The owner of the project, Optimar, produces fish processing equipment. They contacted the university in 2014 because they wanted a solution for the cleaning of one particular piece of equipment that they supplied to fish factories. Manual cleaning had proved unsatisfactory for sustaining a high level of functionality in this equipment. The project objective was to deliver the physical prototype of a robotic solution that could perform automatic cleaning of the equipment in the laboratory. The promising pre-project results led to the three-year project referred to above. During the project, the needs of the industry resulted in an extension to the project, from cleaning one type of equipment to cleaning the whole processing line. When the project was completed at the end of 2018, the outcome was according to the requirements: a robotic solution provided cleaning results that significantly outperformed manual cleaning (Bj∅rlykhaug et al., 2017)(Giske et al., 2019). From a scientific perspective, the achievements were outstanding. However, Optimar did not use the research results and develop the robotic solution commercially.

In order to avoid a similar situation occurring in other university-industry projects and ensure that new knowledge will be used, the researchers that were involved in the Optimar project analyzed how knowledge processes were managed in the project. During the project they had experienced a lack of a methodological approach that could support them in undertaking activities for joint knowledge creation (Perkmann & Walsh, 2007)(Perkmann et al., 2013). The workshops where they discussed the project, project reports, meeting protocols and articles have all provided data for this study. The researchers explain in detail how the novel knowledge management model for university-industry collaboration is applied to the pre-project, the project, and post-project. This article presents findings that indicate that (1) the model has great potential for supporting university and industry in innovation and contributing to building of a collaborative long-term knowledge platform; (2) the model determines the knowledge management initiatives that are the preconditions for successful university-industry collaboration in innovation; (3) the model integrates the industrial user of the research results before and during the project, which is decisive for innovation, (4) methodological application of the model to innovation projects can support sustainable building of the university-industry collaborative knowledge platform. The researchers have used these findings to develop knowledge derived from the project with Optimar to start new university-industry projects.

The following section describes the novel model of knowledge management for university-industry innovation projects. It is followed by the findings with regard to pre-project, project and post-project. Then, the discussion elaborates the results before the conclusion makes suggestions future research.

2. THE NOVEL KNOWLEDGE MANAGEMENT MODEL FOR UNIVERSITY-INDUSTRY COLLABORATION

The three researchers, who conducted the study presented in this paper, were involved in the project with Optimar. One researcher was the project manager on behalf of the university in the pre-project and the project. He has led more than 20 university-industry projects over several years. The other researcher was writing her Master thesis on the pre-project and was later an observer in the project. The third researcher was an industrial PhD student, employed by Optimar.

The researchers applied the novel knowledge management model for university-industry collaboration in innovation projects to analyse the management of knowledge before, during and after the project. Figure 3 depicts the model, which includes the following elements:

A. Operational user's industrial and research need trigger collaboration. Industry's need to find scientific solutions to challenges for technology producers or their customers often initiates collaboration with academia. The researchers identify the respective knowledge gap related to the challenge. This element of the model emphasizes that combination of practical knowledge from industry and the scientific knowledge of the researchers is essential for the success of an innovation project. Only practical understanding of how knowledge is derived from an innovation project can support application of this knowledge in real life.
B. When the need is identified, the knowledge management concepts for collaboration should be in place before any project starts. The concepts consist of the in knowledge management initiatives on three levels: each organization's strategic level (B1 on Figure 3), university-industry strategic collaborative level (B2 on Figure 3) and university-industry project level (B3 on Figure 3). These concepts imply knowledge management initiatives that support knowledge processes during the project and provide for implementation of the research findings.
   B1. Before starting collaboration in innovation with others, university and industry must make a strategic decision for their own organizations about which knowledge disciplines are their areas of expertise, not only currently, but for years to come. These areas must be aligned with regional and national directions for research and development. The concept on the organizational level implies dedication and allocation of the resources for learning and innovation. This is a precondition so that knowledge derived from the innovation

projects will be used and contribute to competence building in the organizations and will strengthen society as a whole. Examples of commitment of the organization to collaboration in innovation with others is when the company or university project managers receive support from top-management to devote time to participating actively in the project's research activities. The opposite is when those involved in the project do not have enough time to work on the innovation project because routine work takes too much time.

B2. After making a strategic decision in their own organization, university and industry must find a partner with whom they can build competence in the long-term. Matching and/or complementary knowledge areas of university and industry define the collaborative knowledge platform. In the local context of university-industry collaboration, the geographic proximity was also an important criterion for choosing a partner (B. Asheim & Grillitsch, 2015). University and industry create a concept for collaboration that defines the direction for partners to build expertise together over five to 10 years ahead. Having people on board that understand both the industrial and academic world is essential for successful collaboration. The absorptive capacity of people involved, their ability to grasp knowledge from one world and use it in the other is imperative to create common understanding in the university-industry setting (Cohen & Levinthal, 1990). Therefore, senior researchers with industrial experience and those in industry that have graduated from institutes of higher education are usually the right people to manage the collaborative projects. The research shows that a well-functioning project group that consists of academics and industry can take the research findings from one innovation project to new projects and develop knowledge further.

B3. On the project level, the concept for collaboration implies that the project objectives should be within the long-term university-industry collaborative knowledge strategy. Facilitation of knowledge exchange, creation and utilization includes creation of an arena that provides common understanding between the partners. For instance, in order for academic PhDs to understand better industrial challenges, he or she can spend some days a week in the respective industrial department. Such integration helps the student to understand the industrial language and builds trust between partners that makes it easier to exchange and build new knowledge. Physical and virtual prototypes have a very important role in communication between the academic and industrial mind-sets.

C. When the knowledge management concepts are in place, university and industry can proceed to the project. The broadly acknowledged organizational knowledge creation model introduced by Nonaka consists of five steps: sharing tacit knowledge, creating a concept, justification of the concept, building of a prototype and cross-leveling of new knowledge (Ikujiro Nonaka, 1994)(Crossan, 1996). This novel knowledge management model suggests modification of the Nonaka's model for the university-industry context by emphasizing that leveling of knowledge across organizations is an activity that must be integrated in all steps of the project and not left until the last step. Moreover, the learning aspect is imperative in innovation (B.-A. Lundvall, 1992)(B.-Å. Lundvall, 2006). Learning is not only exploitation of the knowledge derived from the project, but it is also its exploration, which can lead to new innovation (B. Asheim et al., 2011b). Therefore, the given research emphasis that in the context of university-industry collaboration, new knowledge must be continuously exploited and explored during the project, rather than waiting until the project is finished. The continuous learning during the project is depicted by double-sided arrows from the four knowledge-creation steps of the project to the 'knowledge exploitation and exploration'-step that is defined by sign 'C', and the loop that goes to the 'operational user's industrial and research need' (A) and continues through the 'knowledge management concepts for collaboration' (B) on Figure 3. Continuous learning during the project makes university and industry reflect on the knowledge derived from the project and modify accordantly the knowledge management concepts on all three levels. That creates the double-loop learning that provides for optimization of the organizations' own knowledge strategies and collaborative knowledge platform (Cyert & March, 1963). That has great potential for amplifying the innovation impact from each collaborative project and contributing to strategic building of a collaborative knowledge platform.

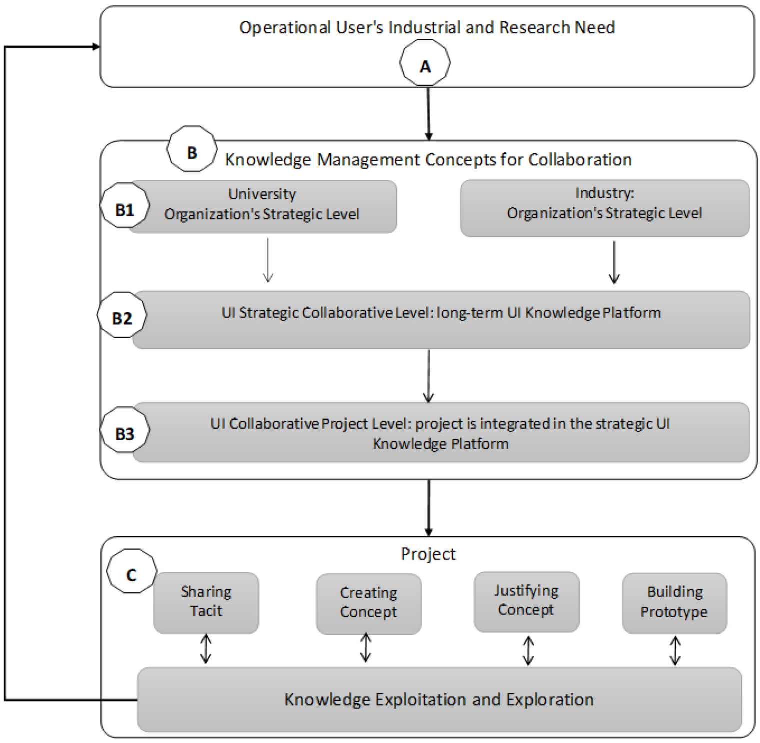

Figure 3: Knowledge management model for university-industry collaboration in innovation projects

3. FINDINGS

Tables 1, 2 and 3 present the evaluation of the main elements of the novel model in accordance with the project progress. Table 21 is the pre-project, Table 22 the project and Table 23 the post project. The following parameters of the model were evaluated in the tables: (1) application of the knowledge management concepts on the three levels to support knowledge processes (B1, B2, B3 in Figure 1), (2) continuing knowledge exploitation and exploration by the university, the owner of the project, Optimar, and Optimar's customers - fish factory (loop C to A and further to B on in Figure 1). Sign '+' means the parameter were applied, and '-' indicates the opposite.

3.1. Pre-project

The pre-project was concerned with the cleaning of the electric stunner, which was a core product for the project owner, Optimar. The customers, fish processing factories, complained about the cleaning challenges of this specific machinery. Developing technological knowledge using a robotic solution was of strategic interest for the university and industry, and partners had plans to continue collaboration in building such competence if the pre-project succeeded. Table 21 depicts the application of the novel KM model for UI collaboration in innovation projects for this phase, where '+' symbols confirms that knowledge concepts on all levels were in place.

To get better insight into the cleaning issues, there were several meetings with Optimar's customer, fish factory, and observations of the cleaning processes at the beginning of the project. The fish factory also participated in the prototype-testing. The prototype confirmed the possibility of using the robotic solution for cleaning the equipment. The customer's enthusiasm about promising technological opportunities led to Optimar initiating a bigger, three-year project, which partly was subsided by the Research Council.

Table 21: Application of the novel KM model of UI collaboration to pre-project

		University	Optimar	Fish factory
Knowledge management concepts	Organizational level (B1 in Figure1)	+	+	
	UI collaborative strategic level (B2 in Figure1)	+	+	
	UI project level (B3 in Figure1)	+	+	
Project	Knowledge exploitation and exploration (loop C-A-B-C in Figure1)	+	+	+

3.2. Project

Industrial needs were expanding in the project period. Optimar defined these needs, without any real discussion with the project team. Optimar found that if the project were profitable there was a need to clean the entire fish processing line, since the value of the cleaning work was too low compared to the investment. Further, there was a need to decrease installation and commissioning time, so this work could be done within 48 hours. That presented a new knowledge requirement: simulation of the process. Microbiology was the other crucial knowledge for the project, so the research institution Nofima, who have expertise in this area, became involved.

During the project, Optimar came into an intensive business period, where the company was bought and new market opportunities arose. The management became less accessible as did the links to the customer, the operational user of the robotic system, the fish factory Martin E Birknes.

Optimar did not have the engineering competence in house, neither the required competence in programming automatic systems. This was not known in the pre project stage.

The project team consisted of the three researchers, project manager on behalf of university, industrial and academic PhD, and the expert from Nofima. Table 22 presents the situation during the project, where '-' symbols regarding Optimar and the fish factory reflect that they were nearly absent during the project.

Table 22: Application of the novel KM model of UI collaboration to the project

		University	Optimar	Nofima	Fish factory
Knowledge management concepts	Organizational level (B1 in Figure1)	+	-	+	
	UI collaborative strategic level (B2 in Figure1)	+	-	+	
	UI project level (B3 in Figure1)	+	-	+	
Project	Knowledge exploitation and exploration (loop C-A-B-C in Figure1)	+	-	+	-

3.3. Post Project

To take knowledge from the project further, the university has entered new projects with industrial partners. Based on the novel model, the researchers have chosen partners that have relevant knowledge fields as the strategic arears for knowledge development in their organizations. These companies are the operational users of the solutions that future projects will provide.

The most important learning outcome from the Optimar project was that fish and seafood processing is an extensive area for research, and that microbiology and technology have to be developed hand in hand. Therefore, the microbiology expert, Nofima, is again a partner in new projects. The university has extended the collaboration inside the university by including the bio- and automation department. This supports the university's knowledge strategy.

Table 23: Application of the novel KM model of UI collaboration to post-project

		University	Optimar	Nofima	Fish factory	Engineering company: software for simulation of production
Knowledge management concepts	Organizational level (B1 in Figure1)	+	+	+	+	+
	UI collaborative strategic level (B2 in Figure1)	+	+	+	+	+
	UI project level (B3 in Figure1)	+	+	+	+	+
Project	Knowledge exploitation and exploration (loop C-A-B-C in Figure1)	+	+	+	+	+

4. DISCUSSION

4.1 Pre-project stage

During the pre-project stage, a robot system was built based on a standard collaborative robot, which was easy to program and use. The cleaning application was related to one single fish-processing machine, an electric stunner. The cleaning job was defined, and quite easy to do. Microbiological measurements were not part of the project. The goal for this project stage was to demonstrate that a robot could clean a fish-processing machine. The pre-project created a foundation for a three-year long main project.

The knowledge management initiatives were in place during the pre-project stage. Involvement of the right knowledge providers and the right people, mutual understanding, and common meeting places were important for establishment of the main innovation project. One interesting observation is that that the fish-processing factory was not involved in the pre-project stage (Table 21). This was most likely a drawback for the main project. It is possible that already at the pre-project stage, some valuable insights in application of robot system could have been communicated from the fish processing factory organization since they were the customer and the user of the robot system. Participation from the fish-processing factory could have created valuable relations and knowledge among all participants in the main project. The fish factory could then have been better prepared for the main project, by allocating human resources and acquiring more insight into how to use a robotic system for cleaning their fish processing equipment.

The university should have presented the knowledge management model to the partners on the pre-project stage. Then, they would have been aware of the importance of their active involvement in the main project stage, in order to fully benefit from the project value. Dedication and allocation of resources for knowledge creation in all three organizations should have been properly planned prior to the project. Therefore, a knowledge management model must include practical guidelines for the university and the industry to prepare partners for execution of projects.

4.2 Project stage

In the project execution stage, the robot systems complexity increased, both in terms of more advanced robots, sensors and cleaning performance. The microbiological domain became more important, since the project included testing of the cleaning performance related to Listeria bacteria. There was more extensive work on building a prototype, both with virtual tools and by physical prototyping. The project also included a full-scale prototype installed in a real fish-processing factory, and microbiological testing for a minimum period of one week. The main project had ambitious objectives for new knowledge and industrial innovations for all partners. This requires extensive and long-term active participation of all partners.

Table 22 shows that the industrial partners were not integrated in the knowledge processes during the project. They did not participate in knowledge creation, exploration and exploiting processes. This led to the outcome that knowledge created by university was not utilized by industry. As knowledge management model proposes, the resources for knowledge creation, exploration and exploitation should be in place to achieve innovation goals. Dedication of resources is demanding for organizations. Therefore, the novel KM model should be extended to a more practical use with a specification that it will secure access to human resources, advanced technical equipment, and financial resources that support innovation processes.

During the project execution stage, the project objectives were redefined by Optimar several times, without involvement of the end user – the fish processing factory. In this situation, the university with other research partners did not have access to the operational user knowledge. Active use of the knowledge management model during the project could have discontinued the project at this stage. The university and the research partners should have asked for more involvement in the project from the industrial partners. Another option could have been to integrate new strategic partners into the project. This would have triggered need for more financial resources, but it could have increased the innovation output from the project. Yet another option was to reject the upcoming industrial needs during the project, by creating a common understanding that it was out of the project's scope. Minor contribution from industrial partners weaken the projects' collaboration platform.

4.3 Post project stage

The post project stage was executed at the university, with extensive reflections on the experience from the project execution stage. The university-industry innovation project delivered significant new knowledge, new products and processes for the industry, and considerable new knowledge for the university. However, from the knowledge management model perspective it was time to rethink how to proceed. The first acknowledgement was the need for the university to put effort into building a sustainable and resilient knowledge collaboration platform, preparing for new university-industry collaboration innovation projects in the future. The building program for the new knowledge collaboration platform consisted of several strategic programs:

- A new master program directed for industrial manufacturing;
- A new master course in digital manufacturing and simulation;
- University owned research project combining the technology domain and the microbiology domain -small scale;
- University owned research project combining the technology domain and the microbiology domain-large scale, research excellence;
- A full scale biotech lab for live fish – industry 4.0 fish processing and robot cleaning;
- A start-up company for commercializing robot cleaning process;
- University funding of 3 PhD positions and 2 post doc positions within the microbiology domain and the technology domain;
- The university employed industrial persons with absorptive capacity who are able to acquire and use knowledge in different research and industrial settings (Cohen & Levinthal, 1990).

A strategic partnership has developed with a fish factory Mowi, the leading global provider of Seafood, and, through new projects and more intensive work, stronger connections were built to Nofima and new technology partners within simulation and industry 4.0 technology.

5. CONCLUSION

The article explores application of the novel knowledge management model for university-industry innovation projects. Active participation research was supported by three researchers in evaluation of the model in the project that aimed to develop robotic cleaning solutions for the fish processing company. The knowledge management model in its existing form does not cover the extensive programs for building of knowledge collaboration platform. However, the knowledge management model gives directions for what is imperative for knowledge exploration and exploitation in innovation projects. The model pinpoints the necessity of involvement of operational user in all stages of the project in order to verify the relevance of the knowledge created. The knowledge management concepts are integral part of the novel knowledge management model. They provide alignment of knowledge strategies with the developing operational user's industrial and research need. The concepts require dedication and allocation of resources for learning and innovation, which is a precondition for innovation project success. Continuing knowledge exploration and exploitation during the project, without delaying till the project end, will lead to greater innovation, provided there is a full commitment from all partners.

The knowledge management model in its existing form can work as a tool for staging of university-industry innovation projects, and it can analyse the operational situation for knowledge management in such projects. However, the model should be improved, so it can support both university and industry to build collaborative knowledge platform in practice. For instance, the proposed model can be extended by incorporation of agile project management tool Scrum (Takeuchi & Nonaka, 1986) (Crossan, 1996). Scrum is used for software development and for traditional project management (Schwaber, 2004). Scrum can be relevant because it has practical approach to target challenges similar to the described in context of university-industry collaboration. Especially Scrum's hands-on review processes with stakeholders within short time-slots can be used to modify product's requirements and to make relevant changes in product development process. Application that is more practical can increase the value of proposed knowledge management model for university-industry collaboration and make it a powerful decision tool. A next step could be to make a program, which collects critical parameters for knowledge processes, knowledge exploration and exploitation for the project. It is also possible to think that advanced algorithms could scan the parameters and generate the proposals on how to solve critical situations, based on analyses of databases from university-industry innovation projects. Application of the model on the bigger number of the university-industry innovation projects can help create a practical version of such model.

However, the main learning from this case study is that the knowledge management model must be put into application with continuous development of the model. Extensive use of the knowledge management model has potential to boost innovation output from university-industry innovation projects.

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SUPPORTIVE PAPER 3

UNIVERSITY-INDUSTRY COLLABORATION PROJECTS: A CASE OF NORWAY.

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Abstract. Innovation often concerns the implementation of research results for operational use. In university-industry collaboration projects, differences in innovation approaches sometimes hinder a project's success. Industrial companies innovate by doing, using and interacting with their stakeholders, applying the so-called DUI mode of innovation. This method of innovation is based on tacit industrial knowledge gained from working experience with products, processes, customers and suppliers. Universities have a long-standing research perspective and use science, technology and innovation—the STI approach, which is based on explicit or codified knowledge. An STI approach focuses on technological solutions rather than users' requirements, so research results often fail to be implemented. Nevertheless, industrial companies need the scientific knowledge of researchers to strengthen their organizational knowledge base and remain competitive in the global market. This article addresses qualitative research on companies that collaborate with universities in research-based innovation projects. Such projects are usually partly funded by the Research Council of Norway and last for three years. Even though many of the projects report innovative outcomes, most of the new knowledge derived from these projects, such as patents and licences, are never used. Different approaches to innovation are some of the obstacles for the creation and implementation of new knowledge in university-industry projects. Our study proposes a set of knowledge management guidelines that can help companies and universities benefit from combining the two modes of innovation (DUI and STI). The guidelines support conversion between tacit and explicit knowledge and are anchored in the SECI-organizational knowledge creation model of Nonaka. Our practical application of the Nonaka's model can reinforce absorptive capacity within universities and companies, so they recognize and utilize the benefits of the other innovation mode. Application of these guidelines can significantly increase the innovation impact of university-industry projects.

Keywords: STI mode of innovation, DUI mode of innovation, university-industry collaboration, innovation projects, knowledge management

1. INTRODUCTION

The study concerns the urgent need to increase the efficiency of research-based innovation projects between companies and universities. Though around 50% of the companies report positive outcomes from the projects such as patents and licenses, the majority of them are never used (*Evaluation of research-based innovation projects*, 2018)(H. Chesbrough & Crowther, 2006)(Powell et al., 2007)(Litan et al., 2007).

The comprehensive studies previously done on the regional innovation systems in Scandinavia emphasize that the combination of two different but complementary modes of innovation is the most efficient strategy to amplify the innovation impact of the collaborative knowledge creation between industry and university (Jensen et al., 2007) (B.-A. Lundvall, 2006)(B. Lundvall, 2007)(B. Asheim et al., 2011a). One is the science, technology and innovation (STI) mode, which aligns with the scientific high-tech research strategy and produces radical innovation. The other the doing, using and interacting (DUI) mode of innovation, which is typical for companies to produce rapid incremental innovation based on tacit industry knowledge of the market and customer demand. Too often academic studies on university-industry collaboration (UIC) take the traditional approach of viewing universities as the provider of scientific codified knowledge to industry and underestimate the power of interactive joint knowledge creation between the university and industry (B. Lundvall, 2007)(Perkmann et al., 2013). This article addresses the research gap regarding how to combine the DUI and the STI modes of innovation by proposing practical guidelines that can be used by the university and industry management to increase the innovation impact of joint knowledge creation and thereby support regions in staying competitive in the globalizing knowledge economy. The proposed practical guidelines consist of knowledge management initiatives that combine the DUI and STI modes of innovation in university-industry (UI) projects and allow the fundamental differences between academic and industrial worlds to be overcome.

Moreover, the study contributes to the organizational knowledge creation theory of Nonaka by applying Nonaka's tacit-explicit knowledge conversion SECI model to the context of university-industry collaboration in research-based innovation projects in Norway. More specifically, the proposed practical guidelines fall into four modes of dynamic knowledge creation processes: socialization (S), externalization (E), combination (C) and internalization (I) that constitute the SECI circle/model (Ikujiro Nonaka, 1994)(Crossan, 1996)(Ikujiro Nonaka et al., 2000). Anchoring the practical guidelines to the theory provides understanding of how and why the suggested management initiatives can support university-industry knowledge creation and the application of the research results from collaborative projects.

The study concentrates on the region on the west coast of Norway that is characterized by limited product related research efforts and incremental process innovation in low-tech branches which mostly include fishery, aquaculture and shipbuilding companies (Narula, 2004)(B. Asheim et al., 2011b). The majority of companies are small-medium size enterprises (SME) that innovate rapidly while 'doing, using, interacting' (DUI) with their customers and suppliers. This innovation is based on tacit knowledge gained from working with products, processes, suppliers and customers. However, to stay competitive in the global market the local industry needs to integrate the scientific, explicit knowledge of researchers anchored in the STI mode of innovation (B. Asheim et al., 2011b)(Jensen et al., 2007)(B. Lundvall, 2007). Therefore, the industry collaborates closely with the local campus of the Norwegian University of Science and Technology. This collaboration is the platform for the 'innovation project for the industrial sector' program (BIA in Norwegian) funded by the Research Council of Norway (RCN). The program promotes regional collaboration between working and research organizations. BIA projects are company-driven three-year long projects that incorporate research activities with a university or research partner/supplier (*The Research Council of Norway*, 2019). The government covers approximately 40% of the BIA project cost.

Nevertheless, economic support is not enough for collaborative projects to succeed in innovation. There are different agendas for collaboration: researchers need to publish while those in industry want tangible results; additionally, different time-perspectives and approaches to conducting projects hinder innovation (I.-E. Hansen et al., 2017).

This study applies qualitative research to analyze how to overcome challenges in combining a university's STI and an industry's DUI modes of innovation. The next section (2) is a brief of the state of the art in the research field. Section 3 explains the research methods applied in this study. Section 4 highlights the challenges of combining DUI and STI modes of innovation in the regional context and why Nonaka's SECI model can be applied to overcome these issues. Section 5 presents and discusses the research findings, which are knowledge management guidelines for UI innovation projects. The conclusion with limitations of the study and future research are presented in Section 6.

2. LITERATURE REVIEW

The prior studies on UI interaction concentrate largely on the input drivers and outputs of collaborative projects and correlations between them rather than managing knowledge processes in collaboration. Academic engagement related to commercialization such as patents, licenses and spin offs (Link & Siegel, 2005) (Perkmann et al., 2013) (Jonsson et al., 2015), the impact of geography and research field proximities on UIC (Laursen et al., 2011)(Petruzzelli, 2011) and cultural differences between universities and industry affecting the UI partnership (Plewa et al., 2005) (Plewa, 2010) dominate the studies in the UI research field.

The study that focuses on managing knowledge processes in innovation projects between university and industry is based on the experiences of Satakunta University of Applied Science (Laine, Leino, and Pulkkinen 2015). Satakunta university's knowledge managing models support industry in decision-making regarding the development of a new technology; the focus is on the application of the STI mode of innovation rather than the combination of STI and DUI modes that requires tacit industrial knowledge in the creation and application of new knowledge.

The literature on university-industry collaboration in innovation highlights the urgent need for study on how to manage university-industry collaboration to provide more innovation (Perkmann et al., 2013).

3. RESEARCH METHODS

Studying knowledge processes in collaborative projects requires understanding of individual experiences; therefore, the qualitative interview was chosen as the most appropriate research method (Perkmann et al., 2013) (Yin, 2016). Fifteen semi-structured, in-depth interviews were conducted including with two academic scholars, one industrial PhD, six project managers from industry and six project managers on behalf of the university.

Two colleagues of the first author were involved in UI collaborative projects during the three-year study of the topic. One colleague was the university project manager and the other was an industry PhD that eventually had to take a role of project manager on behalf of the company. Listening to frequent discussions related to the project between her colleagues allowed prolonged engagement in the field of study and gave real insights into the subject (Lincoln & Guba, 1985). Such a setting provided the opportunity for occasional informal interviews. Nine have been documented.

Additionally, the university's environment with frequent interaction with academics involved in different research projects with industry, was used to arrange a group interview with fourteen PhD students and two senior researchers. The group interview provided additional data for the research.

Furthermore, a project report from one BIA project provided one more perspective on the managing of knowledge processes in UIC projects.

These four approaches to corroborating data refer to the principle of triangulation that seeks at least three different methods of verifying the data to strengthen the credibility of the study (Patton, 2002).

Sorting, reorganizing and interpreting the data resulted in practical knowledge management guidelines for UIC projects (Yin, 2016). These guidelines use the organizational knowledge creation SECI model of Nonaka to combine STI and DUI modes of innovation, which is explained in next chapter.

4. SECI MODEL TO OVERCOME CONTRADICTIONS OF DUI AND STI MODES OF INNOVATION

This chapter explains why the SECI model of Nonaka is helpful for combining DUI and STI modes of innovation.

Collaboration in innovation projects allows organizations to update their knowledge base by exploring and exploiting new knowledge, which contributes to competitive advantage (Huggins & Johnston, 2009)(Huggins et al., 2012). Nonaka presents the organizational knowledge creation process through conversion of knowledge between tacit knowledge (difficult to express in words) and explicit knowledge (codified, documented). Knowledge creation undergoes four conversion processes, including socialization (tacit to tacit), externalization (tacit to explicit), combination (explicit to explicit) and internalization (explicit to tacit) (Ikujiro Nonaka, 1994)(Crossan, 1996). Transitions between tacit and explicit knowledge create an SECI loop that enriches the organizational knowledge base and generates the need for new knowledge, which triggers a new SECI cycle of knowledge creation. In this way, multiple SECI cycles create a knowledge spiral that reflects a continuing dynamic knowledge creation process. Figure 4 depicts SECI model.

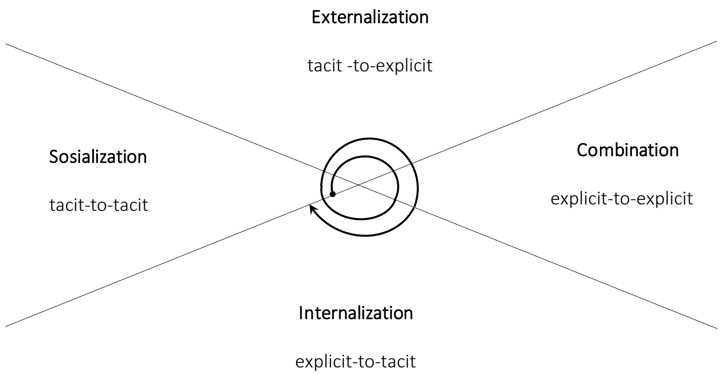

Figure 4: SECI model of organizational knowledge creation (Ikujiro Nonaka, 1994) (Crossan, 1996)

In UI innovation projects, these conversion processes face some obstacles that hinder the combination of DUI and STI modes of innovation and thus hamper creation and use of new knowledge. This is explained further in more detail.

- Socialization. As past research on regional and national innovation highlights, tacit industrial knowledge is crucial in the development of new knowledge in collaborative innovation projects (B. Lundvall, 2007)(B. Asheim et al., 2011b). SME can rapidly sort a) how to solve practical problems, b) who to work with, and c) when it is the right time to introduce and implement innovations. Nevertheless, dedication of the resources to collaborate with universities is demanding for SME's due to limited resources (Lee, 2003). It requires management initiatives that will support industrial tacit knowledge and the understanding of it by the researchers (Brunswicker & van de Vrande, 2014).
- Externalization. Here expectations from the collaboration take explicit form in the documentation of project objectives. When partners have different agendas entering project, the clarification of expectations is a challenge; for example, industry wants tangible results, while academics must publish (I.-E. Hansen et al., 2017).
- Combination. Explicit knowledge can take the form of prototype building. The study demonstrates that industry often leaves this process to the researchers. Academics working alone on a problem can fail to meet industrial requirements. Moreover, if knowledge of the industry is not integrated into the prototype, project results will not be implemented in real life (Mork et al., 2016).
- Internalization. Knowledge or 'learning by doing' converts explicit organizational knowledge into individual tacit knowledge. That usually happens while testing a prototype. As this study indicates, new knowledge continuously derived during the project reveals new industrial and research needs and requires corresponding changes in project objectives and managerial initiatives that will support organizational structures for further knowledge development and applications. Implementation of these changes is often ignored in favor of the initially documented objectives and plans to achieve them and is one of the reasons why research results from a project are not implemented.

Table 24 summarizes the practical guidelines identified for each knowledge conversion process of the SECI model that support the combination of DUI and STI modes of innovation.

Table 24: Application of the SECI model to combine DUI and STI modes of innovation in UI collaborative projects

Conversion process	Practical guidelines to combine DUI and STI
S	Incorporation of the projects in industrial environment Incorporation of students in industrial environment Active engagement of operational users Absorptive capacity of involved people
E	Industry defines the project objectives in research applications Research objectives must address industrial need Research objectives must consider absorptive capacity of involved Clarification and quantification of project results Commitment and quantification of the recourses
C	Integration of realistic data in the project Rapid, frequent prototype building
I	Gradual assimilation of knowledge in both organizations Refining of project and research objectives in the end of each SECI cycle Revising of knowledge management guidelines in the end of each SECI cycle

PRACTICAL GUIDELINES FOR COMBINING DUI AND STI

The following subsections present and discuss the research findings from Table 24 separately.

5.1 Socialization: sharing tacit knowledge between industry and university

The socialization mode establishes success for collaboration. Written specifications are not enough to understand operational users' requirements. Researchers have to become an integral part of a company to comprehend the tacit knowledge of how the DUI innovation mechanisms work in the industrial network. It is also important to understand the industrial organization's history and methods of working with customers and suppliers. This exchange of tacit knowledge between researchers and industry can be a key to common knowledge creation and innovation in collaborative projects. The research specifies how to put this tacit-to-tacit knowledge conversion into practice in the following subsections.

5.1.1 Incorporation of the projects in industrial environment

Key people at SMEs are a scarce resource, and it is not easy to move them from daily operations into innovation projects. A better option is integration of the innovation project into the companies' and customers' operative environment and their daily activities. This opens the possibility for industry to be involved in the project actively and provides the opportunity for productive UI interaction. Additionally, if possible, building prototypes in the real or nearly real environments helps those in industry better understand the implementation benefits and invest in making the research results operational.

5.1.2 Incorporation of students in industrial environment

The research determines that placing students in industrial environments from the project's beginning helps students cognize the industrial value such as complementarity between research requirements and industrial expectations. Daily interaction between students and employees creates trust and mutual understanding that amplifies knowledge exchange, co-creation and application processes (Crossan, 1996)(Krogh et al., 2000). PhD students and MSC students can work with a combination of research tasks and engineering related industrial innovations, for example, product and process development to recognize how the company innovates by DUI with each other, their customers and suppliers.

5.1.3 Active engagement of operational users

Active engagement of operational users, external and/or internal company customers, is critical prior, during and after the project. In the beginning, the researchers and industry should study customers' requirements by going to the actual place and talking to the actual users and trying to experience customers' work routines by performing some of their jobs (Overvik Olsen & Welo, 2011). This can provide insight into customers' tacit knowledge and better present their requirements.

5.1.4 Absorptive capacity of involved people

This study demonstrates that the involvement of people with relevant backgrounds is extremely important. Senior researchers with experience working with industry and project managers in industry understand the requirements and values of academic and industrial worlds. People with these backgrounds are usually capable of effectively communicating knowledge between the university and the company and bridging DUI and STI modes of innovation. They can acquire, create, apply and disseminate knowledge in both organizations and contribute to the development of organizations' absorptive capacities (Cohen & Levinthal, 1990).

5.2 Externalization: from tacit to explicit

Externalization is a process of transforming tacit knowledge into explicit knowledge. In UIC projects this means conceptualization of project objectives, research requirements, expectations from the project and efforts needed to execute the project. At this stage, knowledge takes the shape of documents, contracts and agreements of collaboration in innovation between partners.

5.2.1 Industry defines the projects objectives in research applications

The study indicates that project objectives are imperative for a company's commitment to the project. The objectives must generate the substantial commercial value for the company and the customers/operational users of the technology solution. At this stage, operational users' tacit knowledge is converted as precisely as possible into an explicit form of project requirements. Our research reveals that companies often leave writing funding applications to researchers because they do not have the time or experience to do so. Researchers can describe the need for innovation and propose solutions that address the technology needs from the theoretical perspective, which makes the company less interested in the project and not committed enough to dedicate resources to execute the project and integrate the results. Therefore, a company must invest time and play a leading role in developing the funding application (to RCN) together with the university.

5.2.2 Research objectives must address industrial need

The research objectives must address the technology needs defined by the company in the project objectives. The researchers should demonstrate their understanding of the industrial requirements by illustrating some applications of the technology. It is important that research objectives are made explicit in 'industrial language' quantifying the benefits industry gets from deploying technology solutions.

5.2.3 Research objectives must consider absorptive capacity of involved

The transformation of customer needs and requirements into research objectives must always take into consideration the innovation capability and competence of stakeholders. The knowledge development should be within industrial absorptive capacity, the ability to recognize the value of new knowledge and integrate and apply it in operational environments (Cohen & Levinthal, 1990). The researchers must search for knowledge scope and areas which can be successfully implemented in the industrial companies. The limitations of knowledge can be within technology domains and manufacturing methods, but also regarding knowledge of operational use of new products or processes.

5.2.4 Clarification and quantification of project results

The study indicates that the commitment of partners to the project depends on their clear understanding of what they can expect from the project and partners. The expectations from both sides must be quantified and explicitly described. This includes the specification of the technology maturity level and other performance metrics of the proposed solution.

5.2.5 Commitment and quantification of the recourses

Research demonstrates that a plan for the transition of the research results to real life define who in the company will implement the results. Their competence, time and effort must be qualified for the technology to be deployed.

Often, the only who understand the result of the project are the researchers. When the project ends, and the researchers leave, and there is no one in the company who can make the research results operational. Therefore the company must consider innovation an integrated part of the organizational strategy and prior to the project start should plan to build expertise within the organization (Lazonick, 2005). The positive experience is demonstrated by companies that invest in an industry PhD program that involves company employees earning a PhD linked to the innovation project with a university. It allows candidates to develop knowledge of the company and implement project results.

5.3 Combination: building knowledge through prototypes

5.3.1 Integration of realistic data in the project

Our research reveals that operational users can be skeptical about the application of new knowledge derived from the laboratory to the real world because the gap between experimental and actual context is too great. Therefore, it is important to integrate real data when building or testing a prototype. For instance, when developing a new production process, some of the laboratory equipment should be close to full-scale production equipment in the company.

5.3.2 Rapid, frequent prototype building

This is a step in an innovation project when new knowledge assumes a concrete or tangible form when the concept of new product or process is tested by prototype.

Prototypes are essential for communication, exchange and knowledge building. Iterative processes of building and elaboration of prototypes combine the scientific knowledge of researchers and the practical knowledge of industry, bridging them through STI and DUI modes of innovation (Mork et al., 2016). Frequent prototyping allows for incremental learning and extends the existing knowledge of both partners in a manageable way, progressively increasing the absorptive capacity of both the university and industry (Cohen & Levinthal, 1989).

Furthermore, building prototypes together allows partners to learn from each other by DUI. This experimental method of innovation is authentic to industry, and therefore industry professionals are more open to exchanging, creating and applying new knowledge (H. W. Chesbrough & Crowther, 2006).

Building and testing numerous prototypes elicits feedback from operational users and proves that partners are committed to providing value. This strengthens the trustworthy relationship between the university and industry, which is a precondition for an effective knowledge creation processes (Krogh et al., 2000).

5.4 Internalization

5.4.1 Gradual assimilation of knowledge in both organizations

The tacit knowledge of individuals involved in the project must be disseminated to others in the university and in industry after each prototype build. This study demonstrates good practices of sharing knowledge via PhDs' presentations of project status and workshops demonstrating prototypes from the project. It helps to assimilate knowledge and build competence in both organizations by gradually combining DUI and STI modes of innovation.

5.4.2 Refining project and research objectives in the end of each SECI cycle

Each prototype test allows users to uncover new technological demands. Moreover, the change of external conditions, like political regulations or new technology, impact project requirements. This requires the reevaluation of initial project objectives, which triggers a new SECI loop of knowledge conversion. Each SECI circle supports double-loop learning that enables modification of the project and research objectives and ensures continued value of the project (Argyris, 1991).

5.4.3 Revising of knowledge management guidelines at the end of each SECI cycle

University and industry gain technical knowledge and collaborative experience while going through socialization, externalization, combination, and internalization. They share mental models of technical know-how and ways to collaborate, which becomes an asset for UIC. Each SECI loop must initiate modification of knowledge management guidelines; the partners shall elaborate how they combine DUI and STI modes of innovation and how to benefit more from interactive collaboration processes. Management in both organizations should evaluate the sufficiency of the resources dedicated to the project, their capacities to acquire, assimilate and apply knowledge in academic and industrial environments, places for knowledge creation, and the involvement of operational users.

6. CONCLUSION

This study suggests a practical knowledge management guide for university-industry innovation projects that breaks down barriers by combining STI and DUI modes of innovation in BIA projects. The guidelines are anchored in the SECI knowledge conversion model of Nonaka to accentuate how they help to convert knowledge between tacit and explicit and enhance knowledge creation during innovation processes.

Continuing use of practical guidelines can help universities and industries to build absorptive capacity within organizations, to recognize the value of the other mode of innovation and to gain competence in combining STI and DUI modes of innovation (B. Asheim et al., 2011b).

The research has been done on a small sample of interview objects and limited number of UI innovation projects. The research was also restricted to one region on the west coast of Norway. Nevertheless, the obstacles of collaboration between researchers and industry are similar worldwide and the sharing of experiences and practices can help organizations and regions benefit from combining STI and DUI modes of innovation.

The proposed guidelines for managing knowledge in UI innovation projects require verification. A focus group of the representatives from the university, industry and Norwegian Research Council must evaluate the guidelines. The evaluators cannot be the same people involved in generating of guidelines. The ideal evaluation would be comparing university-industry innovation projects with and without the guidelines applied. This is demanding because of the three-year duration of the project, but the benefit of having such a knowledge management tool can significantly increase the innovation impact of university-industry collaborative projects and drive regional and national economic growth.

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Appendix III: Documents used in the study

INTERVIEW GUIDE FOR SEMI-STRUCTURED INTERVIEWS

Topic: Industry-academia collaboration in research & innovation projects

Date:

Place:

Interviewee:

Interviewer:

Strategy for I-A collaboration in R&I projects

- Is collaboration with the industry/academia integrated in the company's/university's strategy?
- Are the projects aligned with the organizational plans for strategic competence-building?
- Does your organization establish spin off- projects from the existing I-A R&I projects (in case the project opens new research directions)?
- Academia and industry have different interests, working methods, terminology etc. How to establish mutual understanding on the strategic level?
- Are the projects anchored in organizational management?

Project objectives

- How to formulate the project objectives to meet both partners expectations?
- How to formulate PhD research objectives?

Facilitating of the projects

- What is/should be the role of the company in I-A knowledge creation?
- What is/should be the role of the university/academia in I-A knowledge creation?
- What is the role of technology integrator in the projects?
- How to provide common language (mutual understanding) between industry and academia?
- What is the role of prototype building for knowledge creation?
- How often should be the meetings between partners during the project?

Accumulation of knowledge from the project

- How to integrate academic achievements in the company’s knowledge?
- How can industry and academia learn during the projects (not just waiting for the final results)?

INTERVIEW INFORMAL MEETING

Informal interview: notes taking during and right after the interview

Date: 3[d] of December 2018

Interviewee: PL from university

Duration: ca 30 min

Place: university cantina during lunch

- How to support enable collaborative knowledge building?

Need for the people with right attitude from industry and academia. People that can adapt to the changes in the project.

University must select industry partners based on expertise we want to build. It must match the industry's strategies. We (at university) are few resources and have to be selective what we will work on in the future.

Work on a project faster, while one has a momentum.

- How to define project objectives?

I-A R&I projects are very long-term, and rigid. They have a perspective of 5 years if one includes writing of an application and until the project is finished (final report). Therefore, there is a need for another model, which is more adaptive, where one finds people who can contribute, that is the key. Testing this model is important.

The project conditions should allow the fast adaption to the new circumstances (internal organizational and external environmental changes in the marked).

- What kind of resources project need?

One does not need so much money, things should be self-sustaining, a person should not run and organize everything. One can finance resources in a simple way, do not spend time on applicants, but get internal funds.

OBSERVATION FORMAL PROJECT MEETING

Date: 1st of October 2018

Participants: PL from university, industrial PhD

Place: University meeting room

Notes:

- Lack of the resources in the projects. The project needs as soon as possible to produce a mechanical part. They will contact a supplier to the industrial company.

- Communication with stakeholders, common language is important.

- It is important to work fast on building a prototype to move the project forward.

- The customers (fish factories) can see and evaluate the prototype. It will define the next step in the research. Prototype is the crucial platform for communication between stakeholders, both university and industry (fish processing equipment producers, fish factories etc.).

- Project meetings should be held more often in the factory working location (operators will not come to the office room).

- Involvement of the operators is crucial. Their tacit knowledge is necessary for building the prototype. It also gives the ownership to the operators and make them willing to work on project with enthusiasm.

- PhD's work with operators on prototype building supports creativity and trust. Leaning is mutual. Operators learn also from the PhD how to operate robot. It inspires them, gives new ideas for how to produce their other product.

WORKSHOP 'ADDRESSING THE CRITICAL FACTORS IN I-A R&I PROJECTS'

Part 1 (of 3). Presentation of the critical factors in I-A R&I projects by the thesis author- 30 min

Part 2 (of 3). Individual: Workshop participator questionnaire -15 min.

- Current position
- Is your position a part of ongoing research project?
- Do you have experience with other research projects that involve/involved industry?
- If so, how many projects?
- How many years is your academic experience (for how long have you been working at universities or research institutions)?
- Do you have work experience not related to academia? If so, how many years?
- Do you have experience managing the research projects? If so, on behave of industry or on behave of university?

Part 3 (of 3): Discussion in groups

<u>Questions for the discussion part.</u>

Question 1: How to define a strategy for I-A research and innovation projects:

- How can companies and the university/academia avoid sporadic approaches to cooperation?
- How to build relationships in a strategic thoughtful way?

Question 2: How to define project objectives to meet both academic and industrial interests?

Question 3: How to facilitate the project to provide:

- Common language?
- Trust and commitment?
- Individual and collective learning such as both industry and university/academics can learn from the project?

Question 4: How can we learn from innovation projects:

- How can more people from industrial company and university learn about the project?
- How to accumulate knowledge from the project?
- How to retrieve knowledge from the projects?

NOTES WORKSHOP 'ADDRESSING THE CRITICAL FACTORS IN I-A R&I PROJECTS'

Date: 14th of Mars 2018

Place: University

Duration ca 45 min.

Participants: 16 participants total divided into two groups of eight people

Each group: 7 PhDs and 1 senior researcher

1 facilitator for each group (1 is the author of the thesis, the other- one of the supervisors)

Question 1: How to define a strategy for I-A research and innovation projects:

- How can companies and the university/academia avoid sporadic approaches to cooperation?
- How to build relationships in a strategic thoughtful way?

For PhD students difficult to answer. The senior researchers emphasize the alignment of the strategies with the national plans for research and innovation.

Question 2: How to define project objectives to meet both academic and industrial interests?

Companies want often to change the objective during the projects. It is difficult for the researchers, especially for PhD, because they must follow the PhD program and work on the same topic for 3-4 years. Easier if the research is incremental. The company thinks money.

The Norwegian companies usually do not follow the objectives in the contract, they follow the marked.

Question 3: How to facilitate the project to provide:

- Common language?
- Trust and commitment?
- Individual and collective learning such as both industry and university/academics can learn from the project?

The role of the project manager is important. Best if he/she has to have experience both from industry and university.

Very good dialog is needed. Communication is getting better with the time; therefore the PhD can work for a while in the company location. In the beginning of the collaboration, they can work on the tasks that are not related to the research, but important for the company in order to understand their business, their language, and build trust and mutual understanding.

Success rate- record from the previous projects create trust.

Question 4: How can we learn from innovation projects:

- How can more people from industrial company and university learn about the project?
- How to accumulate knowledge from the project?
- How to retrieve knowledge from the projects?

The company WIKI system and publications can be used. Presentations during the research project in the company and in the university can disseminate the knowledge from the project.

EXCERPTS FROM A QUALITATIVE SUMMARY AND ASSESSMENT OF THE IPN PROJECT OPTIMAR-NTNU

Project leader: Optimar AS

Research partner: NTNU Norwegian university of science and technology

Period: 2016-2019

- Competence development (in companies and research environments)

Optimar employed an I-PhD candidate in the company in connection with the Innovation Project. The research field is product and technology development in the Aquaculture industry, which is based on research on Lean Product Development. This is an important investment from Optimar to build competence in-house.

In the project, NTNU Ålesund has employed a PhD candidate in the field of robotics, and this candidate has been central in the development of software and simulation of the washing robot that has been built. This candidate has a main supervisor at the Department of Mechanical Engineering and Production, where they have good expertise in robot programming, which the project has benefited from.

The project has played an important role in building competence at NTNU university, and the project has been linked directly to several subjects. Examples of this are subjects within Entrepreneurship and Innovation, 3D modeling, as well as several Bachelor's and Master's theses. The project has been linked to both the Department of Ocean Space Operations and the Department of ICT and Automation at NTNU Ålesund.

The project has been important for building competence in the processing of fish and seafood. This will be a focus area at NTNU in Ålesund for the future. The project has also exchanged knowledge with the other companies that have been involved in the project, but also with Kleven and Ekornes who are far ahead in robot production and simulation.

- Collaboration and networking

The project has increased the collaboration between Optimar and R&D environments. Several students that Optimar has come into contact with through this project have found work at Optimar upon graduation. Optimar has also hired a student from NTNU Ålesund for summer jobs in both 2017 and 2018. It has also increased the focus on the aquaculture and fishing industry at NTNU Ålesund.

- Utilization of the project results in the company (s)

Some of the spin-off results from the project have already been utilized, especially the focus on hygienic design of equipment and machinery. This provides a clear value for Optimar's customers, as they save time during washing and the risk of bacterial outbreaks is less…

The relationship one has gained with NTNU Ålesund through this project will be important for building up competence in the area.

- Utilization of project results in the R&D environments

NTNU Department of Ocean Space Operations and Construction Engineering (IHB) has built up the subject Industry 4.0 which has the following modules; a) Lean Assembly b) Advanced 3D printing c) Digital Factory d) Robotics. In this subject, the knowledge one has acquired through the project has a central position, and much of what one has learned has gone straight into teaching already. There has also been a flow of people between Kleven, Chalmers and NTNU, and these have contributed to the project and met several employees in Optimar, thus leading to a certain transfer of knowledge.

In the next round, this subject will be a platform for further developing a Master's degree with specialization in Industrial Engineering. The project has provided important knowledge on how to build specially adapted robots for washing food equipment. Furthermore, NTNU IHB hopes to be able to establish a KPN within Smart Production in the Seafood Industry during 2018/2019, where one will benefit further from experiences from this project. Together, this shows a great focus from NTNU on the fishing and aquaculture industry, and this will be important for developing their own competence, and that companies can gain access to the best competence in the national arena (NTNU).

The expertise we have built up will also be used in other research projects. Among other things, they will use the knowledge developed towards the Manulab project at NTNU in Ålesund. It envisages being able to build new knowledge related to automated production of fish and seafood. Here, the focus will be on building new knowledge that covers both technology and biology, as the seafood industry as far as can be seen will be a combination of these subject areas.

One will also follow up with several student projects that address demanding challenges in the seafood industry, both in terms of processing fish and cleaning process lines.

RESEARCH ARTICLES FROM THE OPTIMAR-NTNU IPN PROJECT

1. Experimental study of effectiveness of robotic cleaning for fish-processing plants

Authors: Lars André Langøyli Giske, Emil Dale Bjørlykhaug, Trond Løvdal, and Ola Jon Mork

Food Control, 2019, Volume: 100, s: 269 - 277

2. Development and validation of robotic cleaning system for fish processing plants

Authors: Emil Bjørlykhaug, Lars André Langøyli Giske, Trond Løvdal, Ola Jon Mork, and Olav Egeland

IEEE Conference on Emerging Technologies and Factory Automation, published online: 2017

printed: 2018, s: 1 - 6

3. Improving cleanability by innovating design

Authors: Lars André Langøyli Giske, Ola Jon Mork, and Emil Bjørlykhaug

Journal of Hygienic Engineering and Design, 2017, Volume: 21, s: 3 – 9

4. Hygienic standards and practices in Norwegian salmon processing plants

Authors: Trond Løvdal, Lars André Langøyli Giske, Emil Bjørlykhaug, Ingrid B Eri and Ola Jon Mork

Journal of Hygienic Engineering and Design, 2017, Volume: 20, s: 3 – 11

SURVEY QUANTITATIVE STUDY IPN PROJECTS

NTNU develops practical guidelines for managing IPN projects

What practical project management tools are needed to build more knowledge and encourage more innovation in research-based innovation projects between industry and university?

How can we ensure that research results are used and implemented in the real world and don't end up in the 'Valley of Death'?

NTNU would like to get as much innovation as possible out of collaborative projects with industry. We are therefore contacting you as a project leader for an innovation project in industry (IPN-projects) to ask if you can share what you have learned doing this kind of project. We hope you have 10-15 minutes that you can spare to answer our questions.

Your answers will help to create practical guidelines for project managers of IPN projects.

The survey is anonymous.

If you have any questions regarding the study, please contact me, Irina-Emily Hansen. I am a researcher at NTNU in Ålesund: e-mail: …@ntnu.no, tel.

General Information

1.1. Where have you have worked as a project manager? (you can choose several options)	University	Industry	Research institution
1.2. What was the total budget for your project(s) (you can choose several options)	1 – 6 Mill NOK	6 – 16 Mill NOK	More than 16 mill NOK
1.3. How big were the companies involved in your project(s) you have been working on (you can choose several options).	1-30 employees	30- 250 employees	More than 250 employees
1.4. Did the companies you have worked with have an R&D department?	Yes	No	

Based on your experience with IPN projects, consider how much you agree with the following statements. Answer on a scale of 1 to 5 where 1 is 'strongly disagree' and 5 'strongly agree'.

Stage 1. Project Development

1.	The project team is pursuing new innovations that are emerged from the project.
2.	The project team paves the way for spin offs from the project.
3.	The university uses the innovation project with industry to build knowledge in a long-term perspective
4.	The industry uses the innovation project with universities to build competence in a long-term perspective
5.	Researchers from the university can apply and explain theoretical knowledge in an industrial setting.
6.	The industry's employees are open to adopting new knowledge created in the innovation project.
7.	The management of the industrial company assesses the value of the project results when the project is completed.
8.	The management of the industrial company assesses the value of the project results continuously during the project.
9.	Innovation projects are crucial for the company's future.
10.	The management of university and industry provides full support and independence to the project team.
11.	Both the industrial company and the university allocate the necessary resources to the innovation project.
12.	The company's management approves the work packages and objectives for the project.
13.	The company's management actively participates in the preparation of the project's work packages and objectives.
14.	The steering group reflects on how they can work effectively together and adapts their working methods and attitudes accordingly throughout the project.
15.	Both the industrial company and the university develop their organizations in line with the opportunities that the innovation project presents/generates.

Stage 2. Project Execution

1.	The project team is working in a strategic direction.
2.	End users are involved in the continuous testing of prototypes to find the 'real industrial needs' and to reject 'the constructed needs'.
3.	The technology integrator that is responsible for the industrialization of the research results is involved in the project from an early stage.
4.	Prototypes are built at the industrial company location, so everyone can contribute.

5.	Communication is done by face-to-face meetings, through visualization, and prototype building.
6.	The core team in the project has a common interpretation for the most important knowledge in the project.
7.	All departments in the organization have the opportunity to provide input and learn from the project along the way.
8.	The end user continuously helps to navigate the project's direction.
9.	The customer continuously helps to navigate the project's direction.
10.	The project team works independently and organizes their own progress.
11.	The project has a stable core team dedicated to the project.
12.	The project team reflects on how they can work effectively, and adapts their working methods and attitudes accordingly throughout the project.

Stage 3. Project Evaluation (Learning and application of knowledge)

1.	The needs of industrial companies' customers are built into prototypes and demos, and will thus form the basis for learning during further development.
2.	Ongoing technology development is considered continuously throughout the project.
3.	The end user is involved throughout the project to ensure that the result integrates the practical knowledge needed to use the product.
4.	Stakeholders provide frequent feedback and their knowledge is continuously built into the product.
5.	Demo, prototypes are used to create learning.
6.	Trust and mutual understanding are the basis for effective communication.
7.	Customers of the industrial company evaluate the results and make new contributions to the innovation project at regular intervals during the project period.
8.	Prototypes are built at the industrial company, so that everyone can continuously provide input throughout the project period.
9.	Those who are involved in the project have sufficient time for learning, reflection and knowledge building.
10.	Typical innovators in the industrial company who are experts in the application of knowledge have a central role in the project group.
11.	The project team continually reflect on how they learn and develop new knowledge, and they improve their methods for this throughout the project.

Knowledge exploiting and learning in innovation projects

		Stage 1	**Stage 2**	**Stage 3**
1.	The steering group sticks to its original goals and work packages throughout the project because the research requires a long-term perspective.	**v**		
2.	The steering group adjusts work packages and objectives throughout the project period so that they are in line with technology and the market.	**v**		
3.	Both the industrial company and the university continuously evaluate and allocate resources in accordance with the needs of the innovation project throughout the project.	**v**		
4.	The project work is adapted to the needs of the industry on an ongoing basis, during the project.		**v**	
5.	The research work is adjusted along the way, so that the project meets the needs of the industry.		**v**	
6.	The project team must continuously prioritize what knowledge the project really needs, and discard knowledge that is no longer relevant to the project or the company.			**v**
7.	Frequent iterations and rapid feedback from stakeholders stimulate learning and improvement in innovation.			**v**