INNOVATION ENGINEERING IN PRACTICE

BRIDGING EXPLORATION AND EXPLOITATION IN LARGE MANUFACTURING INCUMBENTS

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Abstract

This thesis explores how large manufacturing incumbents can future-proof themselves by infusing ambidexterity throughout their organizations. In today's rapidly evolving business environment, companies must excel at both exploiting current opportunities and exploring new ones. However, while many large manufacturing companies excel at making incremental improvements, they often struggle to find new ways of creating value for customers, resulting in missed opportunities to stand out in the market through radical innovations. This thesis proposes a methodology consisting of four foundational principles for strengthening the innovation capability of large manufacturing incumbents. The thesis also suggests the term "innovation engineering" to differentiate exploration and exploitation and to demystify exploration-oriented work for the larger organization. Furthermore, it also presents the concept of "intentional PSS design" as an approach to incorporate future aspirations and current capabilities into an evolutionary design process, connecting current and future opportunities, limitations, and possibilities. The thesis proposes tools to support innovation engineering teams in their exploration journeys, which serves to bridge the gap between exploration and exploitation. Through this research, readers will gain a deeper understanding of the potential of innovation engineering and infused ambidexterity, allowing large manufacturing incumbents to adapt to a changing environment and reinvent their ways to meet customer needs. This thesis proposes practical ways to transition from a product-selling to a problem-solving (PSS-solution-selling) enterprise, enabling companies to contribute to solving wicked problems of today and future societal challenges. This thesis will reveal how large manufacturing companies can prolong their lifespan and remain relevant in a rapidly changing business landscape.

Keywords: Innovation engineering, Exploration journey, Organizational ambidexterity, Bridging explore and exploit, Intentional PSS design, Buffer role

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Doctoral Dissertation in Mechanical Engineering

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Abstract

This thesis explores how large manufacturing incumbents can future-proof themselves by infusing ambidexterity throughout their organizations. In today's rapidly evolving business environment, companies must excel at both exploiting current opportunities and exploring new ones. However, while many large manufacturing companies excel at making incremental improvements, they often struggle to find new ways of creating value for customers, resulting in missed opportunities to stand out in the market through radical innovations. This thesis proposes a methodology consisting of four foundational principles for strengthening the innovation capability of large manufacturing incumbents. The thesis also suggests the term "innovation engineering" to differentiate exploration and exploitation and to demystify exploration-oriented work for the larger organization. Furthermore, it also presents the concept of "intentional PSS design" as an approach to incorporate future aspirations and current capabilities into an evolutionary design process, connecting current and future opportunities, limitations, and possibilities. The thesis proposes tools to support innovation engineering teams in their exploration journeys, which serves to bridge the gap between exploration and exploitation. Through this research, readers will gain a deeper understanding of the potential of innovation engineering and infused ambidexterity, allowing large manufacturing incumbents to adapt to a changing environment and reinvent their ways to meet customer needs. This thesis proposes practical ways to transition from a product-selling to a problem-solving (PSS-solution-selling) enterprise, enabling companies to contribute to solving wicked problems of today and future societal challenges. This thesis will reveal how large manufacturing companies can prolong their lifespan and remain relevant in a rapidly changing business landscape.

Populärvetenskaplig sammanfattning

Denna avhandling diskuterar hur stora, marknadsledande tillverkningsföretag kan framtidsäkras genom att ”tvåhänthet”, eller ”ambidextri”, och ett både-och ledarskap genomsyrar hela organisationen. I en snabbt föränderlig värld måste företag vara skickliga på både inkrementell och radikal innovation. Trots att många stora, marknadsledande tillverkningsföretag har effektiva och sedan länge etablerade arbetssätt för kontinuerlig utveckling och inkrementell innovation, saknar de ofta förmågan att utforska och implementera nya sätt att skapa värde, vilket kan resultera i förlorade möjligheter till marknadsfördelar då lovande radikala innovationer inte når marknaden med betalande kunder. För att tackla dessa utmaningar föreslås i denna avhandling ett angreppssätt bestående av fyra grundläggande principer för att stärka företagens innovationsförmåga. Begreppet innovationsteknik nyttjas för att tydligt skilja på utforskande arbetssätt för radikal innovation och det inkrementella. Med innovationsteknik avses i detta arbete både kompetens och process och förståelsen för detta bidrar till att avmystifiera det utforskande arbetet för att skapa radikal innovation. « Intentional PSS design » presenteras som ett angreppssätt för att koppla ihop existerande kunderbjudanden med framtida ambitioner i en evolutionär designprocess som tar hänsyn till dagens och framtidens möjligheter, begränsningar och intentioner. Avhandlingen föreslår verktyg för att guida innovationsteam i deras utforskande resor; verktyg som också kan hjälpa till att överbrygga gapet mellan arbetssätt och förmågor för radikal och inkrementell innovation. I denna avhandling får du som läsare en djupare förståelse för potentialen hos innovationsteknik och en organisatorisk tvåbenthet som genomsyrar hela organisationen. Förhoppningen är att stora tillverkningsföretag kan nytttja denna förståelse för att anpassa verksamheten till en föränderlig värld och ta sig an nya, mer systemorienterade sätt att möta kunders behov och skifta organisationens förhållningssätt från produkt till produkt-tjänste-system-lösningar (PSS). Då kan dessa företag bidra till att lösa dagens och framtidens komplexa samhällsutmaningar.

List of Papers

Paper A

Benaim, A., Larsson, A., Larsson, T.C. & Elfsberg, J. (2014). Becoming an Innovative Company: Assessing an Organization's Innovation Capability from the perspective of a team. Proceedings of the 15th CINet Conference, September 7-9, 2014, Budapest, Hungary.

Paper B

Benaim, A., Elfsberg, J., Larsson, T.C. & Larsson, A. (2015). Implementing Innovation Metrics: A case study. Proceedings of the 20th International Conference on Engineering Design (ICED 15), July 27-30, 2015, Milan, Italy.

Paper C

Elfsberg, J., Larsson, T.C., Johansson, C. & Larsson, A., (2020). Unlocking the full value of a corporate innovation hub. Japan on 6-9 December 2020. Event Proceedings: LUT Scientific and Expertise Publications: ISBN 978-952-335-469-2

Paper D

Amann, M., Granström, G., Frishammar, J. & Elfsberg, J. (2021). Mitigating not-invented-here and not-sold-here problems: The role of corporate innovation hubs. Technovation, 102377. https://doi.org/10.1016/j.technovation.2021.102377

Paper E

Elfsberg, J., Johansson, C., Frank, M., Larsson, A., Larsson, T.C. & Leifer, L.J. (2021). How Covid-19 enabled a global student design team to achieve breakthrough innovation. Proceedings of the Design Society, 1, 1705 - 1714. https://doi.org/10.1017/pds.2021.432

Paper F

Elfsberg, J., Johansson, C., Larsson, A., Larsson, T.C. & Leifer, L.J. (2023). Guiding global innovation teams on their exploration journey. Submitted to journal.

Paper G

Elfsberg, J., Larsson, A., Larsson, T.C., Johansson, C. & Root S. (2023). Lost in translation between explore and exploit: From selling products to solving problems in large manufacturing incumbents. Submitted to journal.

Author’s contribution to the papers

Paper A

Paper A presents a study conducted with both an inside and outside perspective through close collaboration between academia and a company. The author led the company's innovation-strengthening initiative from 2009 to 2018, providing insights into the company's organization, conditions, and dynamics. The study highlighted the disconnect between innovation aspirations and daily deliverables in the company's R&D organization. The research team identified the company's "do not disturb" approach, meaning that the innovation strengthening initiative should not cause disturbance to near-term deliveries. While top leadership communicated a strong commitment, it was not cascaded down the layers. Many middle managers and engineers considered the initiative a disturbance or an optional activity. The insights from the study were used to adjust the continued work led by the author, capturing observations and contextual implications for both the corporate initiative and the academic research. The study also included observations and insights from an experimental implementation of an online tool for reporting indicators and metrics, with room for iterative improvements.

Paper B

As the main responsible at the company, I collaborated with the other authors to design and conduct company-internal, cross-departmental workshops. Together, we compiled a list of potential metrics specific to the company, selected a set of metrics, and refined the set with input from management teams and key individuals. I then led the global implementation of the final set. We utilized semi-structured interviews and online surveys to gather context-specific research data for this study, which in my case was inspired by participatory action research methodology. Our research team balanced my company-specific insights with theories and experiences from other contexts. Having me as a practitioner involved was crucial to prevent confusion and misinterpretation, given the company's complex organizational structure, globally dispersed workforce, and organizational changes. Adaptability and anchoring internally were necessary for our research as well as the company's innovation-strengthening initiative.

Paper C

I led the study, which spanned from August 2018 to August 2020 and was also the principal author of the paper. Initially, the data was collected as my journaling notes, with a focus on learning from other heads of corporate innovation hubs in Silicon Valley. At the same time, I designed and established the hub for my employer. The "pay-it-forward" mindset, prevalent in Silicon Valley, led all respondents to generously share their experiences, learnings, mistakes, and networks, and all that rich data led to the design of a study where semi-structured interviews followed by an online survey generated rich data which was then analyzed and discusses leading to research findings As an additional step to validate the findings before finalizing the paper they were shared with the respondents in the study.

Paper D

This paper summarizes the M.Sc. thesis of Marie Amann and Gabriel Granström, with Johan Frishammar serving as their academic supervisor and myself as their industry supervisor. I played a crucial role in designing the study, which aimed to identify strategies for successful corporate innovation hubs. The study included respondents from Silicon Valley and various global corporate headquarters. My primary contributions were in the study's design, data analysis, and paper writing.

Paper E

This single case study was possible due to an ongoing multi-year study where the research team shared journaling notes and observed matching patterns across different student teams. With the onset of Covid-19, I collaborated with Christian Johansson Askling and Martin Frank to design a deeper study on team dynamics and performance, involving more students and focusing on their individual perspectives. The concept of a supporting cohort was defined through the close collaboration between academic and corporate partners. I led the data collection and analysis and identified a typical team journey map, which represents the pattern that emerged from the multi-year study. The rest of the research team provided valuable insights and critical questions based on their long-time involvement in the course.

Paper F

The author has been conducting a multi-year study aimed at understanding the performance and learning experience of student teams involved in a graduate student course. Based on findings presented in paper E, the author developed the concept of a supporting cohort and two tools for it: the team journey map and the hunter-gatherer map. The study involved data collection from students each year, and patterns were identified to guide the design of the supporting cohort tools. The hunter-gatherer map was first tested in the study presented in a previous paper, with input from the rest of the research team, who provided their perspectives based on their experience in similar courses. The author led the design of the study, collection and analysis of data, the identification of patterns, and the paper writing process.

Paper G

As the lead researcher, I conducted a study on multiple cases of Product-Service-System solutions that failed to generate revenue. The data for this study was collected over several years through journaling notes and semi-structured interviews with employees involved in the cases. I also interviewed leaders from other manufacturing companies to explore whether the gap between exploration and exploitation was common. One of the authors contributed with both an in-depth understanding of how a large manufacturing incumbent managed to ways of bridge exploration and exploitation and by connecting to a respondent from the former HP Labs organization. The visualization model used at HP, The Wonder Bread model, has been incorporated into this research as it has not been described elsewhere. The other co-authors provided academic expertise and theoretical perspectives.

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First and foremost, I would like to express my utmost gratitude to the Knowledge Foundation (KK-stiftelsen) for funding the MD3S - Model Driven Development and Decision Support research profile, and to both Blekinge Institute of Technology (BTH) and Volvo Group for their long-term commitment to the research profile. Without this my research journey would never have been possible.

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I owe a debt of gratitude to Volvo Construction Equipment's Emerging Technologies team, the iCoach network, and the entire Advanced Engineering team at Volvo CE for their trailblazing work from 2009 to 2018. Similarly, the pioneering original hub335 team in Mountain View motivated and enabled my continued research from 2018 to 2020. Building and leading these outstanding teams has been an amazing opportunity for my personal development as well as for my research journey.

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Thank you all <3

“The scientist describes what is; the engineer creates what never was.”

Theodore von Kármán

1. Introduction

1.1. Background

Revolutionary innovations like Spinning Jenny, the steam engine, electricity, the telegraph, and the combustion engine have through history followed the pattern of first disrupting, then transforming, and finally stabilizing a new order until the next revolutionary innovation emerges. Innovations based on digital technologies, such as smartphones, location tracking solutions, and the industrial internet of things (IIoT), are not following this pattern due to the way performance in computing, storage, and bandwidth improves exponentially (Hagel et al., 2008), and because scaling of digital technologies is not limited by physical nor geographical constraints. When a seemingly mature industry's underlying technologies develop in this nonlinear way, a stable phase might never occur. This dynamic requires of large firms to anticipate, adapt, and develop a future-shaping strategy in order to stay competitive (Hagel et al., 2008; Wadhwa et al., 2020; O'Reilly & Binns, 2019), i.e., to futureproof themselves.

Large manufacturing incumbents are global market dominant manufacturing companies that once were startups that succeeded in growing from initial market launches to scaled, long-term sustaining businesses with powerful positions, world-wide, as customers, employers, suppliers, and partners. Those incumbents have continued to stay competitive mainly by exploiting their existing revenue streams (Stadler, 2011). Examples of large manufacturing incumbents with impressive long-term competitiveness are:

The Gillette Company, the shaving razor firm, now part of Procter & Gamble, was founded in 1901 by King C Gillette, who invented the first safety razor ever and has continued to dominate the razor and blade market through incremental innovations like the first cartridge, multi-blade cartridges, a battery-powered razor, a pivoting razor, and an extended product portfolio with shaving and grooming products (McKibben, 1997).

Husqvarna Group, the power tool maker, founded in 1689 as "Jönköping Rifle Factory" by decree of the Swedish monarch, is today a leading manufacturer of chainsaws and other power tools for gardening, forestry, and construction. Husqvarna owes its longstanding success to the engineering know-how acquired in the development of lightweight and high-precision machinery and combustion engines in sewing machines, household machines, bicycles, mopeds, motorcycles, chainsaws, lawnmowers, etc. In 1969, Husqvarna was the first chainsaw manufacturer with an integrated anti-vibration system, and the company's focus on ergonomics and safety has generated continuous innovations aiming at outstanding productivity, durability, and reliability (Husqvarna, 2023).

Volvo Construction Equipment, Volvo CE, is today a world-leading construction equipment manufacturer and part of Volvo Group. Volvo CE has its beginnings in 1932, when Bolinder-Munktell, BM, was founded as a result of a merger between two engineering workshops; one was founded by Johan Theofron Munktell in 1832, and the other was founded by Jean and Carl Gerhard Bolinder in 1844. BM developed, manufactured, and assembled combustion engines, locomotives, harvesters, tractors, and other farming machines and was acquired by Volvo in 1950. In 1954 the company launched the world's first wheel loader and, in 1966, the world's first purpose-built articulated hauler. The company has continued to develop the wheel loader and the articulated hauler, added other machine types through acquisitions, and explored new solutions enabled by technology advancements, such as autonomous, hybrid electric and fully electric, and connected machines (Volvo Construction Equipment, 2023).

Through incremental innovation (O'Reilly & Tushman, 1997), (Cole, 2002), large manufacturing incumbents develop new product generations, extend the life of existing ones, refine their processes to become more efficient, and find new customer segments to drive revenue growth (O'Reilly & Binns, 2019). The most long-lived manufacturing incumbents have developed innovation strategies that allow them to both exploit their existing revenue stream and explore ways to create new ones (O'Reilly & Binns, 2019; O'Reilly & Tushman, 2013; Tushman & O'Reilly, 1996; Gupta et al., 2006). Some large manufacturing incumbents intend to beat the odds of disruption by creating separate innovation units, where new concepts are explored and developed, often together with external partners and niche customers. It is common that those separate units operate independently, with their own mindsets, processes, and mechanisms, but with access to the larger corporation's assets and resources (Christensen, 1997; Christensen et al., 2018; O'Reilly & Tushman, 2019).

Examples of companies applying this approach are IBM with their EBOs (emerging business organizations), Lockheed with their Skunk Works, HP with HP Labs, Ford Motors with Greenfield Labs, and Xerox Corporation with Xerox PARC (O'Reilly et al., 2009), (Vitton et al., 2018), (Single & Spurgeon, 1996), (Banerjee et al., 2010), (Hilzik, 1999). The separation approach can be both effective and convenient for large, profitable companies. Still, there is a risk that the disconnect between the innovation unit and the larger organization leads to those promising radical innovations, conceptually proven and highly desired by partnering niche customers, never reaching the market (Blank, 2014).

As industry dynamics are changing, for example, through the advancement of information and communications technology, i.e., electronics hardware, software, and telecommunications, new market entrants rapidly grow from being startups to becoming major players (Archibugi & Iammarino, 2002; Osterwalder, 2004). Some new entrants rapidly scale and become multinational, market-dominant corporations. Some of them credit their company culture and their innovation strategy for their successes. Google's company culture is one example (Girard, 2009), where employees have since the beginning been encouraged to work wherever they feel is best for them, as long as the job gets done adequately and promptly, an approach adopted by others after the Covid-19 pandemic, as a way of attracting and retaining talent (Turner, 2023). Through a flat organizational structure, Google promotes openness and transparency, and all employees are encouraged to share their opinions. The company claims that it stretches goals to eliminate all forms of restrictions an achievable goal may bring. Google believes that the employees make the company and treat them accordingly (Girard, 2009). Amazon has an approach where innovation is everyone's job, which is guided by leadership principles and mechanisms, and an organization consisting of separable, largely autonomous teams which allow for rapid decision-making with minimal need for escalation (Bryar & Carr, 2021). Netflix similarly fosters a culture of freedom, responsibility, and reinvention, where leaders are instructed to lead with context, not control (Hastings & Meyer, 2020), which means that intent, conditions, and dependencies are well understood, and employees are given agency to contribute in the way they decide is best. In the automotive industry, Tesla is an example of a new entrant causing disruption and industry transformation away from fossil fuel to electric vehicles. Tesla operates a vertically integrated business model, i.e., the company (together with its many partners) designs, develops and operates manufacturing facilities for its cars, electric motors, battery packs, and stationary energy storage systems, sells all its products online, or in company-owned physical stores, and performs over-the-air software updates without any other interface than the one between the car owner and the company (Lang et al., 2021). Tesla's industry-shaping approach contributed to the transformation from fossil-fuelled cars to electric ones, with a strategy addressing the ecosystem on all levels, i.e., overturning the core product architecture, positioning themselves in key bottleneck components, and resolving system-level limitations that otherwise slow the adoption of the technology, i.e., building and providing the EV charging infrastructure (Furr & Dyer, 2020). Through their industry-shaping approach, Tesla has built a strong innovation capital, attracting engineering talents and investors (Dyer et al, 2018). The innovation capital can be described as:

- who you are and your capacity for forward-thinking, creative problem-solving, and persuasion,
- who you know that can contribute with valuable resources for innovation,
- what you've done in terms of both track record and reputation, and
- the things you do to generate attention and credibility.

Other game-changing companies are Airbnb, Uber, and Lyft (Mlodawski, 2019) - providing lodging and transportation solutions without needing to own vehicles or real estate. Another example, highly relevant for large manufacturing incumbents with the aim to stay relevant and competitive over time is SpaceX, which develops and manufactures space launch vehicles, rocket engines, crew spacecraft, and communications satellites, being the first private company to take humans out in space, and first in the world with deploying fully reusable space launch vehicles (Seedhouse, 2022). SpaceX have five project management principles that allow them to rapidly develop and deliver new solutions (Thomas, 2018):

- Deep dive into fundamentals, i.e., make sure to understand the basics,
- Effectively communicate information and ideas, i.e., convey and transmit necessary pieces of information across diverse work groups to promote coordination,
- Enhance leadership abilities, i.e., leaders must demonstrate that the team and all individuals work hard and contribute,

- Effectively manage time, i.e., a fast-moving, accurate, achievable time schedule is key to success,
- Control costs, exemplified by being first in the world with reusable rockets and by optimizing project objectives to minimize the cost of progress.

When new competitors enter an industry, offering novel and attractive solutions based on information and communication technologies, large manufacturing incumbents need to respond; therefore, they need to understand, embrace, and integrate new technologies into their business models (Osterwalder, 2004). With a zoomed-out, holistic approach, physical and digital components can be bundled into integrated solutions (Tucker & Tischner, 2006), which requires new business models and potentially also shifted company identities – from being product makers to becoming problem solvers by offering Product-Service-System (PSS) solutions. Wikhamn et al. (2013) observed how the truck, bus, construction equipment, and combustion engine manufacturer Volvo Group started making this shift in the early 2000s. The intention was to shift Volvo Group's business model from selling products to selling complete value-based solutions, enabled by the rapid development of telematics and other digital technologies (Wikhamn et al., 2013). For a large, multinational manufacturing incumbent, this requires a dramatic change of mindset, from focusing on maximizing sales volumes to focusing on long-term relations with customers across their total life cycle. The term "soft products" was coined as a definition of embedded software and other immaterial aspects of value offerings, and also a clear contrast to the company's traditional "hard products" (Wikhamn et al., 2013).

In a large mature firm, where the culture and corporate identity is product-oriented and technology-driven, the shift from products to PSS solutions is far from intuitive and requires a change of organizational structure, business strategy, goals, culture, measures, and work processes, on all levels (Wikhamn et al., 2013). This is both demanding and difficult, but there is no alternative for large manufacturing incumbents wanting to be future-proof in a complex and exponentially changing world (Diamandis & Kotler, 2017).

A large manufacturing incumbent will have better chances to future-proof itself if equipped with organizational ambidexterity, i.e., the ability to balance exploration and exploitation (Duncan, 1976; March, 1991; Tushman & O'Reilly, 1996; O'Reilly & Tushman, 2016). Balancing between the two means that the incumbent remains competitive in its core markets and simultaneously wins in new domains. This tends to require partnership with other companies, contributing with necessary expertise in rapidly developing knowledge domains where the incumbent is unable to keep up. Furthermore, future proofing of incumbents requires innovation capability, which includes the firm's abilities, skills, and routines to convert knowledge into technology and thus into business (Zawislak et al., 2012), as well as the ability to attract and retain top talent (Culp, 2022). The combined effect of rapid technological advancements and the urgent transition toward a sustainable society (Grin et al., 2010) requires large investments in research and innovation, systems thinking (Voulvoulis et al., 2022), and new value constellations (Rahnama et al, 2022). For large manufacturing incumbents, this means that the stable and predictable business-as-usual approach becomes outdated. The traditional relation between the incumbent and different "tiers" of suppliers might not be efficient when value is provided to customers from different providers that continuously develop, optimize, and deliver in an interdependent value constellation (Ai Qiang Li et al., 2022). As many established manufacturing industries have exhausted the possibilities in the evolutionary development and refinement era, it becomes necessary to make fundamental step changes (Isaksson & Eckert, 2022). This new era requires re-invention on a system level. Engineering contributions in early, disruptive phases of innovative product and service system development are critical and requires other culture, mindset, tools, and methods than what characterizes evolutionary product development. Additionally, engineers must not work in isolation but instead act in an integrated ecosystem of companies, combining units of expertise and synchronizing with societal actors. In most large manufacturing incumbents, the R&D function is organized around different engineering design disciplines, such as mechanical, electrical, and structural engineering, and innovation-related skills are generally not recognized as core competencies, not even in companies with a clearly stated strategic intent to balance their investments in both exploring new potential solutions and exploiting existing ones (O'Reilly & Tushman, 2013).

Large manufacturing incumbents need to anticipate the future and adapt to and adopt emerging technologies and practices to futureproof themselves. There is a clear long-term trend of declining corporate longevity, and the few companies that historically have stayed competitive over time have one thing in common, and that is that they have been able to take their assets and capabilities and move into new businesses (O'Reilly & Tushman, 2016).

Organizational ambidexterity requires understanding and action on all levels in organizations. Top leadership need to understand the importance and the nature of both exploration and exploitation and be willing to invest in and promote both. Leadership levels below the C-suite also need to understand exploration and exploitation as equally important and fundamentally different. On the level where actual knowledge-building and development work is done, it is common that exploitation-oriented processes, tools, methods, guidelines, checklists, and core competencies are well-defined, continuously improved, and followed up, while exploration is often left underdeveloped and considered too “fuzzy”, or too unimportant to document, or treated as it needs to fit into exploitation ways of working. Engineers involved in both exploration and exploitation might experience how exploitation projects are carefully followed up with performance metrics, well-defined stages and gates, and task forces if problems occur, while exploration projects are often not tracked at all. This unbalance sends an implicit message to the engineers and their leadership that exploitation is important and prioritized while exploration is optional.

1.2. Aim and research questions

The fundamental problem addressed in this research is that most large manufacturing incumbents are unbalanced between exploration and exploitation. While they have optimized their ways to stay competitive through exploitation, they do not see exploration as an equally important capability for long-term competitiveness and futureproofing. Organizational inertia, bureaucracy, risk aversion, process and decision-making inflexibility, and lack of innovation capability might be reasons that promising proven concepts, coming out from exploration projects rarely transition from proof-of-concept to scaled revenue generation. This is a problem because market disruption can happen in all industries and markets, and if you are not actively exploring how to disrupt, you are at risk of being disrupted. Another problem to address is that when companies invest in exploration that does not lead to financial return, the investment is a waste of resources and time, as well as lost opportunities.

This research aims to increase the understanding of how to futureproof large manufacturing incumbents by making exploration and exploitation equally prioritized and by managing exploration effectively. The research objective is to develop a deeper understanding of:

- How to strengthen and maintain innovation capability in large manufacturing incumbents.
- How to better support exploration processes and practices in large manufacturing incumbents, and how to guide innovation teams carrying out exploration projects.
- How to integrate exploration with exploitation in large manufacturing incumbents and thus accelerate the innovation process and improve the likelihood of radical innovation concepts reaching the revenue-generating stage.

When addressing leaders within large manufacturing incumbents, this research aims at providing insights regarding what exploration is, how to support and guide employees working with exploration, how to integrate exploration with exploitation in the broader organization, and how to increase the likelihood and the speed of successful exploration project outcomes to generate value for the customers and the company. In addition, when addressing innovation teams and team members carrying out exploration projects, the aim is to contribute with insights that help the individuals to perform better as a team and to increase the likelihood of a successful outcome. Here, a successful outcome can mean both acquired knowledge and conceptually proven solutions.

To address the research objectives described above, the following research questions are formulated:

RQ1: How can large manufacturing incumbents strengthen their innovation capability?

RQ2: How can exploration be institutionalized, guided, and led in large manufacturing incumbents?

RQ3: How to bridge exploration and exploitation in large manufacturing incumbents?

RQ4: How might bridging between exploration and exploitation help a large manufacturing incumbent to shift its business orientation from products to product-service systems?

1.3. Delimitations and reader guide

The scope of this research is limited to the context of large manufacturing incumbents. In these organizations, a focus on operational excellence, and optimized ways of working, have led to state-of-the-art product, project, and quality management, cost control, resource utilization, and efficiency. In these firms, one commonly finds streamlined processes and routines for the exploitation side of the businesses, including the Toyota (Liker, 2003) inspired philosophy of continuous improvement. Most large manufacturing incumbents also invest in exploration; some apply best practices found in literature, others have developed their own approaches. It is common that the understanding of exploration needs to be improved, and related processes, governance models, competencies, methods, and tools need to be developed or better implemented and integrated.

Most large manufacturing incumbents have financial stability, the long view of market shares, assets, inventory, headcount, competencies, and ambitions to take exploration seriously. Large, mature firms often have a well-developed, multi-year strategy that guides them in balancing their R&D spending wisely (Nagji & Tuff, 2012). Still, there are many challenges for organizations to establish and maintain innovation capability, to bridge between explore and exploit, to develop new business models for novel integrated solutions, and to gain a financial return on investment from their exploration activities. In addition, it is challenging for company leaders to navigate the complex landscape of potential disruptions due to fastmoving technological advancements, customer behavior changes, geopolitical instabilities, and other uncertainties. Companies must build on their strengths and core competencies while simultaneously anticipating what’s coming and adapting to emerging technologies, practices, and market conditions (Wallin et al., 2022).

This thesis summarizes research rooted in empirical studies and observations from the industrial practice I have led from 2009 to 2020. As a reader, one needs to pay attention to the fact that this has been an iterative and explorative journey performed by an industrial Ph.D. student while directly involved in the industrial practice.

2. Theoretical background

This study focuses on large manufacturing incumbents; successful goods-producing companies that hold leading positions in their industries and markets. These companies primarily generate profits by exploiting their existing businesses, with a particular focus on meeting the needs of their most sophisticated customers (Christensen, 1997). In various sectors such as energy, infrastructure, transportation, automotive, electronics, medical, and technology, large manufacturing incumbents create jobs, invest in manufacturing facilities, inbound and outbound logistics, and international import and export, all of which contribute significantly to countries' gross domestic product (Tödtling & Trippl, 2005). These companies might also contribute with significant environmental and social impacts, ranging from resource depletion and emissions to worker exploitation and human rights abuses (Liu et al., 2018). Therefore, it is crucial for large manufacturing incumbents to adopt sustainable practices to mitigate their negative environmental and social impacts (Markkanen & Anger, 2019). Large manufacturing incumbents have an advantage in identifying their customers' unmet needs and developing new solutions ahead of the competition due to their market dominance and customer knowledge (MacMillan & Selden, 2008). This advantage positions them to seize opportunities through leading market positions, technological advancements, and expanding their businesses from product sales to integrated customer solutions (Butt, 2020). However, leadership within large manufacturing incumbent organizations is often characterized by a preference for process-oriented thinking and risk aversion (Ford et al., 2014; Henderson, 1993; Levitt & March, 1988; Leonard-Barton, 1992; Christensen, 1997; Bergek et al., 2013). Leaders in these organizations typically place significant emphasis on the current state of the organization's business operations while grappling with the considerable burden of fulfilling quarterly financial reporting obligations. Attention is often focused on the efficient management of expenses related to inventory and operations, as well as the pursuit of research and development initiatives. Moreover, leaders may feel an obligation to satisfy the expectations of stakeholders, such as company owners and investors, who have high expectations for positive financial outcomes and growth. Given increasing geopolitical uncertainties and rapidly evolving technological advancements (Boyes et al., 2018), it is crucial for large manufacturing incumbents to cultivate both agility and ambidexterity (Ohr, 2020). This means being able to anticipate and adapt to external threats and opportunities while simultaneously exploiting existing strengths and exploring new avenues for competitive advantage. In light of the research context and aim, the following subchapters describe the primarily related knowledge domains on which this research builds. The structure of the theoretical subchapters is based on three focuses: first, a focus on the corporate level; second, a focus on processes for exploration; and finally, a focus on capabilities in teams conducting work of explorative nature.

2.1. Futureproofing on the corporate level

Large manufacturing companies are operating in an ever-changing and unpredictable business environment driven by market competition, emerging technologies, new customer expectations, and geopolitical factors. To remain relevant and competitive in the long term, these companies must be able to anticipate potential challenges and opportunities, adapt to changed market conditions, and respond quickly to any other changes that occur. Futureproofing of a large manufacturing incumbent involves several key elements, including strategic foresight (Rohrbeck & Schwarz, 2013; Carleton et al., 2013), exploring emerging technologies (Rotolo et al., 2015), and exploring new practices (Cammarano et al., 2023). It is also essential for companies to experiment with new business models (Christensen, 2006; Santos et al., 2009) to shape their future and that of their industry. While it may be difficult for a large manufacturing company to become entirely futureproof, developing the ability to anticipate, adapt, and leverage emerging opportunities can significantly increase its chances of overcoming disruption. In the following subchapters, we will delve deeper into some of the elements of futureproofing that need to be tackled on a corporate level.

2.1.1. From products to PSS

To strengthen their continued competitiveness, large manufacturing incumbents can expand their business beyond physical product sales into functional sales, integrated solutions, total business solutions, or Product-Service-System (PSS) solutions (Sandström, 2011). However, failure to adapt to new technologies, customer behaviors, and new entrants can cause large manufacturing incumbents to lose dominant market positions and customer loyalty (Pereira et al., 2017). According to Pereira et al. (2017), established companies shift towards PSS solutions for the following reasons:

- Strategic issues - to protect the market position and create an entry barrier for new competition,
- Customer demands - to co-create value and establish a long-term partnership,
- Low environmental impact trends - to drive sustainability.

A PSS solution is a combination of physical and digital components provided to customers as a bundle. The bundled solution can be offered through different business models that are product-oriented, use-oriented, or result-oriented (Tucker & Tischner, 2006). See Figure 1.

A product-based customer offering is visualized to the left, which is when the business model is based on transactional sales and the user purchases the product. To the right, a pure service-based customer offering is visualized and exemplified by teleportation. Other examples of pure services are management consultancy services, law firm and bank services, and airlines services. In between, different solutions based on the combination of products and services are visualized. A product-oriented solution is, for example, a user-owned car with a contracted service agreement; a use-oriented solution is, for example, an electric scooter owned by a provider and used by many in a city center; a result-oriented solution is, for example, a paper printer solution where you pay-per-copy, lighting equipment where you pay-per-lux or a material transport solution where you pay per transported volume/weight and kilometers. The choice of the business model determines the relationship between the customer and the provider/providers. It might enable reuse, repurposing, re-manufacturing, and recycling, thus increasing resource productivity and minimizing waste generation (Laurenti et al., 2015).

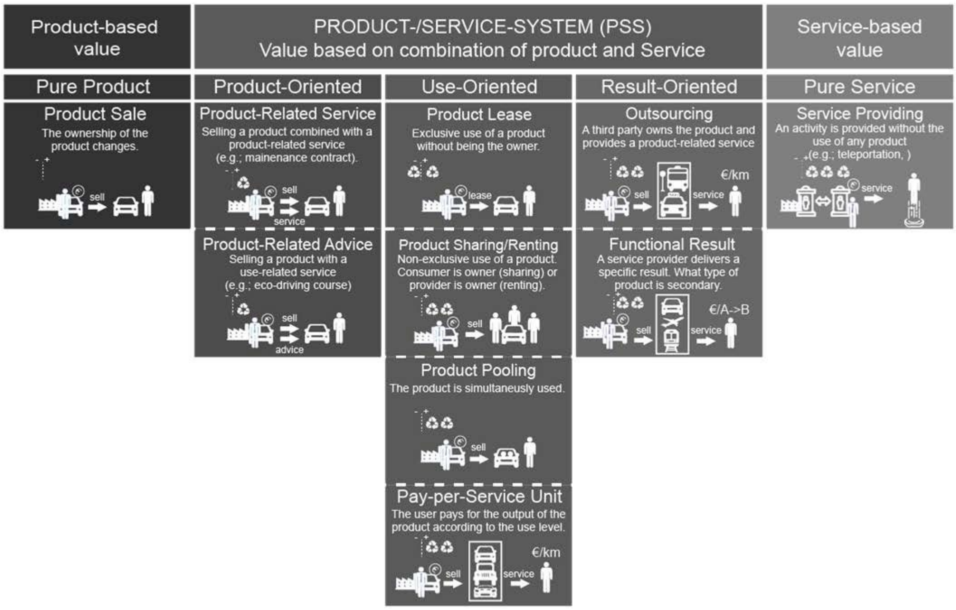


Figure 1. Product-Service-Systems, adapted from Tucker and Tischner (2006).

Expanding a business model from product-based to PSS oriented requires business model innovation (Christensen, 2006; Zott & Amit, 2010). Business model innovation is a process where established companies significantly change how they operate. This intentional process allows them to tackle challenges and opportunities in novel ways, with the potential to increase market shares or disrupt markets where they compete.

However, business model innovation for large manufacturing incumbents is different from that of new organizations, as it requires reconfiguring existing internal and external activities (Santos et al., 2009). Santos et al. (2009) suggest that corporate executives start this process by engaging leaders in creating a new context where leaders across the organization can undertake the transformational process. It is crucial to remember that people and relationships are as important as technological linkages and economic exchanges (Santos et al., 2009).

This becomes particularly important for large manufacturing incumbents that have focused on optimizing processes and logistics for a linear economy, mass production, product volume sales, and transactional business models for decades, or even centuries. However, digital and connected technologies, such as Industry 4.0, enable a shift towards a more sustainable, resource-efficient, or even circular economy (Arekrans et al., 2021).

Digitalization changes the industry's internal ways of working and its' ways of doing business (Mikalef & Parmiggiani, 2022). Transformative changes impacts automation, industrial manufacturing, supply chain management, agile and lean production, and total quality management (Kristoffersen et al., 2020), as well as product development, people management, financial administration, etcetera. Improved sharing of information throughout the value chain helps to control and make real-time adjustments of operations according to varying demand (Moeuf et al., 2018) which enables new forms of partnerships, so-called "coopetition" (Bengtsson & Kock, 2000). Larsson et al. (2010) suggest that these changes will require new development processes as well as new engineering competencies in the following domains:

- Systems and interface,
- Creativity and methods for the systematic idea and innovation management,
- Integrated product and process planning and design.

Shifting a company's business model from products to PSS solutions may require a complete reconfiguration of the firm's operating model and knowledge management strategies. The burden of the necessary reconfiguration process of "what is" needs to guide the way forward rather than an idealized future of "what might be" (D'Ippolito et al., 2019). PSS solutions involve a mix of technical, social, and digital designs, leading to the emergence of new value constellations and partnerships. A systemic approach can be applied in the early stages of conceptual design (Lugnet et al., 2020), as well as early simulation and decision support models (Jones et al., 2019).

Large manufacturing incumbents must prioritize digital technologies on the same level as physical artifacts to remain competitive in the market, as customers increasingly expect integrated solutions that incorporate both digital and physical components, known as cyber-physical systems (Bertoni & Bertoni, 2019). However, shifting a company's focus towards integrated product-service systems (PSS) will necessitate significant changes in strategy, business models, organizational structures, operations, design, and engineering processes (Gaiardelli et al., 2021). In contrast to traditional product development, which is sequential and engineering-centric, developing cyber-physical integrated solutions requires collaboration and input from multiple disciplines within the organization and with partnering customers and others (Bertoni & Bertoni, 2019; Wallin et al., 2015). PSS solutions must be viewed as holistic concepts rather than separate product and service units (Wallin et al., 2013). This approach can be facilitated by methods and tools focused on value creation, as well as company-wide restructuring towards a new perspective and the development of new capabilities (Lenka et al., 2017).

2.1.2. Corporate innovation strategy

The term "innovation" refers to "the introduction of something new" or "a new idea, method, or device" from Latin. Schumpeter (1934) defined innovation as the outcome of an entrepreneur's work creating new combinations and changes in the economy's business environment, including new products or services, methods or processes, markets, sources of raw materials, or organizations. Furthermore, Schumpeter (1934) wrote that these new combinations could be a new product or service, method or process, market, source of raw material, or a new organization. Tidd and Bessant (2021) suggest four forms of innovation:

- Product or service innovation,
- Process innovation,
- Position of innovation due to changes in the context,
- Paradigm innovation due to changes in the company's mental models.

Innovation is essential for survival and growth (Tidd & Bessant, 2021). Therefore, large manufacturing incumbents need to take innovation seriously, regardless of their current performance. For this reason, a corporate innovation strategy is crucial to a company's longevity, addressing both "the why" and "the how" (Christensen, 1997; Chesbrough, 2017; Osterwalder, 2020; Kaplan, 2012). Tidd and Bessant (2021) point out that innovation is driven by entrepreneurship, which within large manufacturing incumbents is sometimes called "intrapreneurship." Intrapreneurial capability is necessary for the renewal of both customer offerings and internal operations (Tidd & Bessant, 2021), enabling the extension of the company's domain of competence and the creation of new business opportunities so that the company can evolve (Burgelman, 1984). The process of innovation can be described as an exercise in managing and reducing uncertainty (Kline & Rosenberg, 1986). Moore's (1991) technology adoption life cycle (see Figure 2) consists of stages that represent changes in a technology's life cycle based on how the public views, buys, uses, and understands the technology. The life cycle span depends on the technology; for example, digital technologies have shorter life spans than physical ones.

The stages can be defined based on who the buyers are:

- Innovators, who innovate and develop new technology,
- Early adopters, who are enthusiasts and want or need to adopt technology quickly,
- Early majority, who are open to new ideas and innovations but slightly more conservative than early adopters,
- Late majority, who become adopters after the early majority,
- Laggards, who are the most conservative in accepting and adopting new technology.

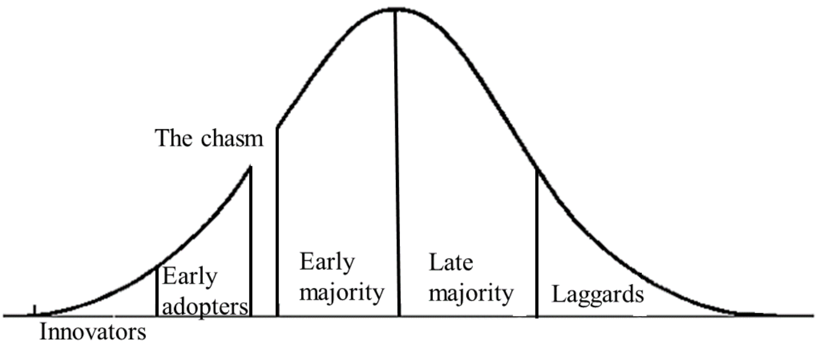


Figure 2. The technology adoption life cycle, adapted from Moore (1991).

The technology adoption cycle might also be used when diagnosing an organization's internal approach towards a technology, both in terms of internal use and in terms of adopting it as part of an integrated customer solution. Then, to "cross the internal chasm" would mean that the organization is ready to adopt the technology. The technology adoption cycle can help companies to determine whether they should sustain, expand, or extend their core (Gibson, 2015), where core refers to functions, processes, assets, and capabilities that generate value provided to existing customers.

A corporate innovation strategy needs to clearly define how resources are allocated (i.e., funding, staffing, equipment, etcetera), and Nagji & Tuff (2012) observed that the most successful, long-term sustaining industrial companies manage a "total innovation system" where they balance their innovation portfolio between different types of innovation. They suggested that for large, mature industrial firms, the following ratio was optimal:

- 70% to safe bets in the company’s current core,
- 20% to less sure things in the adjacent spaces,
- 10% to high-risk transformational initiatives.

The ratio is approximate and was, at the time of the study, specific for large, mature industrial firms, while other company categories were recommended other numbers (Nagji & Tuff, 2012). In the model Nagji and Tuff (2012) presented, see Figure 3, core innovation initiatives correspond with incremental innovation, which can be both changes to existing products and incremental inroads into new markets. Transformational initiatives, designed to create new offers or even whole new businesses, to serve new markets and customer needs, are also known as breakthrough, disruptive, or game-changing innovations. Adjacent innovations can share characteristics with core and transformational innovations. It can, for example, mean leveraging something the company does well into a new space or a novel technology provided to known customers. Adjacent innovations allow a company to draw on existing capabilities but necessitate putting those capabilities to new use.

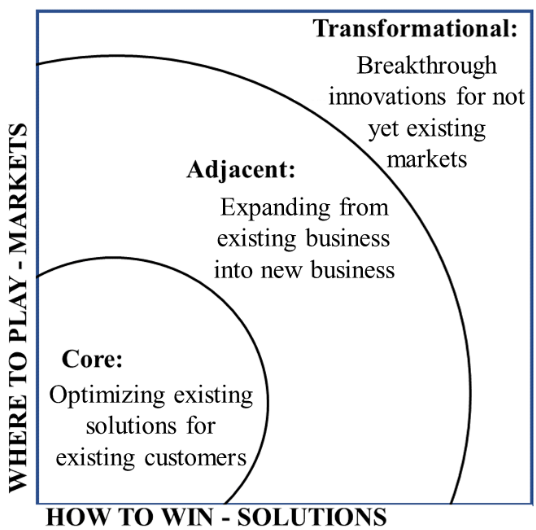


Figure 3. Three main types of innovation, adapted from Nagji and Tuff (2012).

Another approach to R&D portfolio balancing is the three horizons framework (Baghai, Coley & White, 2000); see Figure 4. Horizon 1 represents the core businesses most readily identified with the company name and those that provide the greatest profits and cash flow. Here the focus is on improving performance to maximize the remaining value. Horizon 2 encompasses emerging opportunities, including rising entrepreneurial ventures likely to generate substantial profits in the future, but that could require considerable investment. Horizon 3 contains ideas for profitable growth down the road—for instance, small ventures such as research projects, pilot programs, or minority stakes in new businesses.

Recent horizon models also include Horizon 4, addressing a bold vision, an almost impossible future, or a "moonshot" (Goldman et al., 2016; Diamandis & Kotler, 2015), where anticipated future scenarios and opportunities to shape an envisioned future can be addressed. Exponential technologies (Diamandis & Kolter, 2012) challenge the way incumbents have planned and managed their competitiveness and longevity and might make formerly accepted mental models and methods obsolete. Products and services are transformed, and industries are disrupted when computational power is not a limiting factor, when everyone and everything is connected through the internet, and when the delivered value to paying customers can be provided without the need to involve physical artifacts (Wadhwa, Amla and Salkever, 2020).

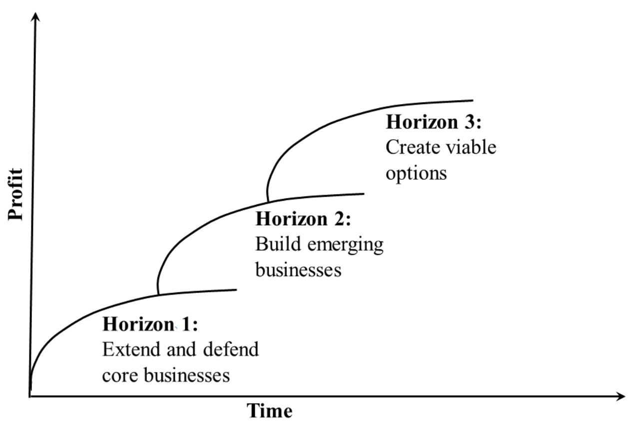


Figure 4. The three horizons model, adapted from Baghai, Coley & White (2000).

In the long-term perspective, innovation is necessary for survival, and, therefore, large manufacturing incumbents invest in different innovation initiatives. Some are more effective than others. Steve Blank coined the term "innovation theater", referring to inefficient ways of addressing the innovation challenge in large mature firms. Blank (2019) explains the different types of theater as follows:

1. Organizational theater - often guided by external management consultants, leadership seeks to solve the challenge with innovation through reorganization alone,
2. Innovation theater - activities like hackathons, design thinking classes, and innovation workshops with an emphasis on creative confidence, where leadership seeks to solve the challenge with innovation through activity experiences only,
3. Process theater - reforming and recasting processes and metrics optimized for exploitation execution, where leadership seeks to solve the challenge with innovation solely with reformed processes.

Blank (2019) writes that many large organizations lack shared beliefs, validated principles, tactics, techniques, procedures, organization, budget, etc., to explain how and where innovation will be applied and its relationship to the rapid delivery of new products. Furthermore, Blank (2019) claims that an innovation doctrine is needed. In this doctrine, culture, mindset, and process must be considered to guide the organization's efforts to achieve real innovations.

2.1.3. Innovation culture

In an empirical study, Kahle et al. (2017) observed that the most successful organizations, when it comes to fostering innovation and creativity, have a culture where innovation is institutionalized throughout the entire organization rather than the responsibility of one separate unit. Furthermore, Kahle et al. (2017) observed that intrinsic motivators for innovation are more consistently effective than extrinsic motivators (i.e., rewards, competitions, external threats, etcetera). Intrinsic motivators include a sense of purpose, pride in work, and personal engagement. Therefore, the most significant drivers of innovation are the system for innovation and the clarity of a proactive strategy that encourages widespread participation in innovation and guides the direction toward it (Kahle et al., 2017).

A good innovation culture has, according to Pisano (2019), the following characteristics:

- Tolerance for failure but no tolerance for incompetence,
- Willingness to experiment but highly disciplined,
- Psychologically safe but brutally candid,
- Collaboration but with individual accountability,
- Flat but strong leadership.

A culture of innovation requires several key factors, including tolerance for productive failure, psychological safety, collaboration, and flat organizational structures (Aagard & Gertsen, 2011; Balsamo et al., 2008; Denti & Hemlin, 2012; Smith et al., 2008). High-performance standards are essential to explore novel technologies and create new business models, with no tolerance for incompetence (Pisano, 2019). To progress learning and knowledge building, failure should be productive rather than caused by incompetence, and highly disciplined experimentation should capture learnings systematically and test hypotheses at the lowest possible cost (Pisano, 2019; Sitkin, 1992; Khanna et al., 2015). A culture of candid debate is crucial to improve work, with brutal candor, referring to respectful critique of ideas, methods, and results (Pisano, 2019; Edmondson, 2018). Senior leaders must establish this culture by inviting criticism of their own ideas and proposals (Pisano, 2019; Edmondson, 2018). Individual accountability paired with collaboration can help the team avoid groupthink and improve decision-making (Pisano, 2019; Edmondson, 2018; Kamau-Mitchell & Harorimana, 2008).

2.1.4. Organizational ambidexterity

When an organization is ambidextrous, it embraces both incremental innovation and radical innovation as important capabilities for its near-term and long-term competitiveness. This requires an understanding of the two different disciplines; one which can be planned and controlled based on existing opportunities and known limitations, i.e., exploitation, and one where an intent needs to suffice as direction for identifying new opportunities and creating new solutions, i.e., exploration. Tushman & O'Reilly (1996) refer to exploitation as incremental and evolutionary change and exploration as discontinuous or revolutionary change. When an organization simultaneously pursues incremental and discontinuous innovation, i.e., both exploring and exploiting, it is an ambidextrous organization. Some of the main differences between exploration and exploitation are listed in Table 1.

Table 1. Explore vs. exploit, adapted from March (1991), Smith & Tushman (2005), Holmqvist (2004), Hughes et al. (2010).

Exploration	Exploitation
Innovation and growth	Cost, profit, and efficiency
Entrepreneurship, search, discovery, and risk taking	Operations in focus, selection, refinement, implementation
Loose in control and process, flexible, adaptive, and agile	Formal structure, well-defined process execution
Radical, breakthrough, revolutionary or disruptive innovation	Incremental innovation, continuous, evolutionary improvement
Visionary and involving leadership	Top-down, command-and-control leadership
Experimental, iterative process with uncertain outcome	Predictable, linear process with certain, predetermined outcome
Ambiguity preserved	Clarity through limitations and choices

Ambidexterity is a term derived from Latin and means “both right” or “both favorable”. Organizational ambidexterity means that the organization has established capabilities and resources to continuously manage both exploitation of the existing and exploration of new opportunities (Tushman & O’Reilly, 1996). Organizational ambidexterity needs to be managed at multiple levels in large, mature firms (Kassotaki et al, 2019), e.g., 1) the organizational level (strategic), 2) the inter-firm level (internal dependencies and relationships between functions or units), and 3) the external environment level (dynamism, complexity), or 1) the firm level, 2) the project level, and 3) the employee level. Furthermore, Kassotaki et al. (2019), point to the importance of having ambidexterity management on multiple levels and across levels so that tension between exploration and exploitation can be actively managed horizontally, vertically, and throughout the entire organization. A “both-and” leadership is necessary in all functions and on all levels.

Burgelman (2002) suggests that ambidexterity management requires both resource allocation rules for balancing between exploration and exploitation, and strategic leadership capability for linking between exploration and exploitation. Strategic leadership capability is necessary on all managerial levels and is particularly important for middle management. It includes being able to provide strategic direction to employees, building a network of support from peers, and helping scale promising initiatives. This enables top management to have sufficient confidence to support, protect, and embrace the promising initiatives.

Tushman and O’Reilly (1996) suggest that exploration should not be seen as separate from the larger organization but rather as enabling the reconfiguration of existing resources and the development of new capabilities, which is easier said than done. Exploitation and exploration activities are different in terms of strategic intent, critical tasks, competencies, structures, control/rewards, cultures, and leadership roles. Organizational ambidexterity can be achieved in at least three different ways, as presented in Table 2 (Stoetzel & Wiener, 2013; Gibson & Birkinshaw, 2004; Birkinshaw et al., 2016; Tushman & O'Reilly, 1996).

Table 2. Types of organizational ambidexterity, adapted from Stoetzel & Wiener (2013), Gibson & Birkinshaw, (2004), Birkinshaw et al., (2016), and Tushman & O’Reilly, (1996).

Type of ambidexterity	What it means
	Conflicting objectives and tasks are divided as organizational level (different sub-units, or internal vs. external).
Temporal, punctuated or sequential	Conflicting objectives are pursued by the organizational unit temporarily in cyclical phases.
Contextual or behavioral	to divide their time between conflicting tasks.

The structural separation of explore and exploit subunits, each with its own established processes and cultures aligned to their missions, enables top-down strategic alignment despite very different goals, mindsets, dynamics, and approaches (O’Reilly & Tushman, 2011) but might also cement the company’s identity as a product-oriented one and by that limit renewal since most employees and processes will be oriented towards revenue-generating exploitation (O’Reilly & Tushman, 2013).

Contextual ambidexterity, also known as behavioral ambidexterity, is an approach that addresses the tension between exploration and exploitation throughout the organization. This approach utilizes stretch, discipline, support, and trust to empower individuals to make decisions about when to allocate time and resources to exploration versus exploitation (Gibson & Birkinshaw, 2004). However, contextual ambidexterity can be difficult to manage since exploration and exploitation demand different time horizons, skill sets, performance metrics, and characteristics (Gupta et al., 2006). Temporal ambidexterity, also known as punctuated or sequential ambidexterity (O’Reilly & Tushman, 2013), is often applied by having long periods focused on exploitation punctuated with short bursts of exploration, maybe as an innovation-oriented two-week sprint in an agile development environment, or as a corporate-wide event focused on innovation – an innovation jam, innovation days or any other time-boxed focus on exploration.

Temporal ambidexterity temporarily removes the organizational tension between explore and exploit, but the switching between the two is far from easy and requires unique capabilities to be an efficient approach (Chou et al., 2014). Although the concept of organizational ambidexterity is well documented in the literature, and the different approaches are explored in multiple different case studies, it is not sufficiently investigated how large, geographically dispersed organizations can establish ambidexterity, how to manage it over time and how to bridge between explore and exploit practically.

2.1.5. Innovation capability

Innovation capability is defined by Lawson and Samson (2001) as the ability to continuously transform knowledge and ideas into new products, processes, and systems for the benefit of the firm and its stakeholders. Innovation capability is not only about successfully running a business's "newstream" or managing mainstream capabilities. It is about synthesizing these two operating paradigms (Lawson & Samson, 2001). Studies have repeatedly shown that incumbents' ability to create and adapt to non-incremental innovation differs starkly from their ability to deal with incremental innovation (Henderson & Clark, 1990; Christensen & Bower, 1996; Maula et al., 2006). Incremental innovation is commonly integrated into large manufacturing incumbents' continuous improvement programs, often based on the Toyota Way (Liker, 2003), while non-incremental innovation activities tend to be dealt with as a separate side activity. Some of the non-incremental innovation efforts are completely autonomous, i.e., only require involvement of, and only impact company-internal products and resources, and some are systemic innovations, i.e., require significant adjustments in other parts of the system they are embedded in (Teece, 1986; Chesbrough & Teece, 1996; Teece, 1996; De Laat, 1999; Maula et al., 2006). The three different forms of non-incremental innovations are:

- Radical innovations – that change core technical concepts and their linkages – create adaptive challenges for incumbents (Tushman & Anderson, 1986).
- Architectural innovations (Henderson & Clark, 1990) – another term for innovations that change the linkages between core concepts.
- Disruptive innovations - interrupt or disrupt an existing market and create a new one by providing a different set of values, which ultimately and unexpectedly, overtakes the existing market (Bower & Christensen, 1995).

Non-incremental innovation threatens large manufacturing incumbents by being both game-changing and unexpected. O'Reilly and Binns (2019) suggest that large mature firms need to master the processes of ideation, incubation, and scaling to beat the odds of disruption. Ideation is the process needed to set an ambition or strategy for exploration and to generate ideas with the potential to realize these goals. Incubation is the process of using evidence to evaluate and validate an idea, including knowing when to kill the idea and when it is time to scale it. Scaling is the ability to convert successful experiments into revenue-earning businesses that generate sustainable revenue. Besides mastering ideation, incubation, and scaling, companies need to apply a blend of acquiring, building, partnering, and leveraging existing assets and capabilities to succeed (O'Reilly & Binns, 2019).

Table 3. Four dimensions of strategies against disruption, adapted from Wallin et al. (2022).

	Focus on internal development efforts	**Stance on new entrants**	**Ecosystem strategy**	**Rules of the game**
Exploit strategies	Strengthen existing capabilities	Create entry barriers to sustain status quo	Secure keystone position in future ecosystem	Maintain prevailing institutions
Explore strategies	Invest in radical innovation	Cooperate with disruptive entrants	Facilitate innovation in ecosystem	Break or change the rules

Table 3 presents four dimensions that executive leaders in large manufacturing incumbents consider when developing strategies against disruption, according to an empirical study by Wallin et al. (2022). These dimensions are addressed either with an exploitative approach or an explorative approach. In the study, the researchers found that executive leaders tend to look for disruption caused by technologies and innovations, changes in market demand and supply, institutional and systemic shifts, and the company's own inability to change. According to Wallin et al. (2022), a winning strategy might be a combination of addressing all four dimensions.

Commoditization, i.e., the process by which goods that have economic value and are distinguishable in terms of attributes (uniqueness or brand) end up becoming commodities in the eyes of the customers, expecting lower price and higher quality, leads to that manufacturing processes rather than product innovations become the basis of competition (e.g., Utterback and Abernathy, 1975). Commoditization happens over time, and a linear, incremental innovation process works well to tackle that challenge, while rule-breaking actions tend to be unplanned and triggered by opportunities that arise in serendipitous ways (Burgelman & Grove, 2007), a dynamic that is much more difficult to tackle for large manufacturing incumbents. Novel, disruptive technologies that suddenly become good enough to change the basis of competition (Christensen and Bower, 1996) can also be difficult to adopt for large manufacturing incumbents with most resources allocated towards exploitation strategies, lack of competence in the emerging technologies, and strategic technology partnerships not established and often take time to establish. It is also difficult to manage business model innovation because it transcends the focal firm's boundaries, but it is nevertheless possible to do so. A firm can target certain actors and avoid others (both inside and outside existing customer organizations), experiment with different value propositions, try out alternative distribution channels, and change its revenue models (Sandström et al., 2014).

To identify strengths and weaknesses in developing an organization's innovation capabilities, it is essential to measure. To measure an organization's innovation capability requires an integrated approach that combines qualitative and quantitative measures across different categories (Richtnér et al., 2017; Nilsson et al., 2010; Kaplan, 2017). Denti (2013) proposes that the following categories are included:

- product/technology measures,
- financial measures, and
- subjective measures.

Nilsson et al. (2010) suggest a framework called MINT (Measuring Innovation Capability in Teams), consisting of four areas, see Figure 5. The four areas, combined with factors corresponding with metrics related to those four areas, form a framework that allows for a unique set of metrics suitable for the specific organization's ambitions, needs, and characteristics so that the organization applying the framework considers the metrics relevant and meaningful. Richtnér et al. (2017) similarly suggest a framework consisting of three phases: A) Assess current innovation measurement practices, B) Develop or improve metrics related to portfolio, process, and projects, and C) Deploy the improved innovation measurement practices. There is no perfect plug-and-play model for measuring innovation performance in large manufacturing incumbents. Still, to draw attention to what is not urgent and not directly connected to the near-term financial results, it can be helpful to collect information and analyze what you see. When the mission is to strengthen the organization's innovation capability, implementation of a holistic innovation measurement system that makes sense to the organization can be an effective first step.

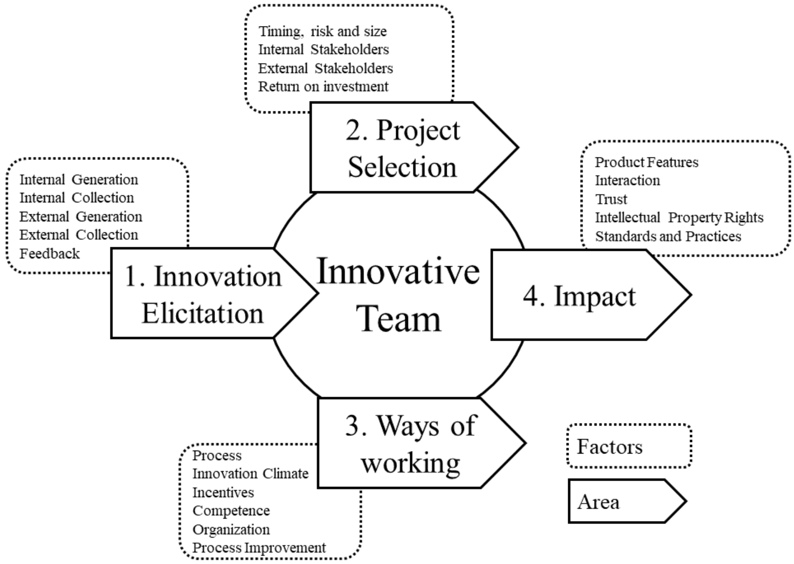


Figure 5. The MINT framework, with areas and factors, adapted from Nilsson et al. (2010).

2.2. Exploration process

Engineers within large manufacturing incumbent's R&D function are often managed as scarce resources and allocated to multiple development projects running in parallel (Zika-Viktorsson, 2002). Project managers lead well-defined exploitation-oriented projects with clear scopes, approved budget frames, and critical path timelines. The time available for engineers to perform their tasks is limited by the hours allocated to projects, deadlines that need to be met, and other constraints in the projects they are assigned (Motamediyan et al., 2012). When too many projects are assigned to engineers, maybe in an effort to maximize efficiency, there is a risk that engineers experience a lack of time for recuperation, psychological stress reactions, limited time for skill development, and stifled innovation (Motamediyan et al., 2012). Most engineers in large manufacturing incumbents are trained and used to follow a linear product development process where high performance in the five dimensions of product quality, product cost, development time, development cost, and development capability leads to economic success (Ulrich & Eppinger, 2014). In the large manufacturing incumbent, the product development process also includes purchasing, manufacturing, marketing, sales, and aftermarket, and room for fixing mistakes or making design iterations is limited (Ulrich & Eppinger, 2014). This is the nature of exploitation and where most of a large mature firm's engineers spend their work time. The nature of exploration is diametrically different from this, requiring different engineering skills, different engineering mindsets, and different performance metrics. Engineers solve problems by creating artifacts or systems, often before scientific understanding is available and before the public has identified a need (Hammack & Andersson, 2022). Engineers create structures, devices, and systems that revolutionize the world, for example, ocean-crossing airplanes, life-saving medicines, glass-and-steel towers, lithium-powered cell phones, cellular networks, and spacecraft journeying outside our solar system (Hammack & Anderson, 2022).

2.2.1. Engineering design

According to Dym et al. (2005), the definition of engineering design is a "systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraint". Bylund et al. (2004) suggest that it is a decision-making process that transforms needs and requirements into verified solutions, where limitations like lead time and cost restrict the outcome of the work. McMahon (2021) suggests that a broad description of engineering design includes three perspectives that should be considered:

- how design varies in different situations and contexts,
- how design exploits past experience using design patterns, and
- how design actions explore new possibilities or exploit existing understanding.

McMahon's (2021) description indicates that engineering design practice depends on the context and the time era in which it is being performed. This was observed by Carleton & Leifer (2014) when they listed key phrases in course descriptions for a graduate student course that has evolved over 50+ years, see Table 4.

Table 4. Engineering design education evolution, adapted from Carleton & Leifer (2014).

Years	Key phrases in course description
1967-1974	Synthesis based on examination of artifacts and records from interviews and case histories
1972-1974	Immersive process based on project work accompanied by investigation of the design process
1974-1981	Real world problems provided by industrial sponsor and solved by a small group of students
1981-1990	Mechatronics where the student team learn smart product design, manufacturing, and design methodology, supported by industrial coaches
1990-1995	Redesign where the student team learn to rapidly prototype and test, ending with a full-scale functional product prototype presented to industrial audience
1995-1998	Teamwork where the student team is interdisciplinary and geographically distributed, team-based design and development with industrial partners
1998-2004	Entrepreneurship, tools for team-based design, business environment and detailed specifications of solution. Team acts as a small start-up company
2004-2009	Global innovation teams performing project-based engineering design, innovation, and product development
2009-	Foresight, where the teams learn anticipatory research and the art, science, and practice of design innovation in a globally distributed interdisciplinary team

Dym et al. (2005) observed that human-designed solutions are becoming increasingly complex, partly because more robust designs are desired and partly because environmental and societal impact needs to be integrated into the design process. This has led to engineering design practices have evolved towards a more holistic practice, which can also be noted in the education evolution presented in Table 4. One capability which is essential in current engineering design practice is systems thinking, which according to Dym et al. (2005), means: a) recognizing the system's context, b) reasoning about uncertainty, c) making estimates, d) performing experiments, and e) making design decisions.

2.2.2. Front-end innovation processes

The front-end of the innovation process is sometimes called the fuzzy front-end because it is considered to be the least structured part of the innovation process, both in theory and in practice (Herstatt et al., 2004). The notion of the fuzzy front-end was first introduced by Smith and Reinertsen (1991), who suggested a list of approaches to shorten product development time, which included the recommendation of a systematic approach to the fuzzy front-end and the advice to build a reserve because not all concepts will be successful. One way of demystifying the fuzzy front end is to focus on the output from it, described by Khurana and Rosenthal (1998) as:

- the project concept (clear and aligned with customer needs),
- the product definition (explicit and stable), and
- the project plan (priorities, resource plans, and project schedules).

Activities in the front end of the innovation process are often difficult to anticipate, overview, and perform (Frishammar & Florén, 2010). The front end of the innovation process is the period between when an opportunity for a new product is first considered and when the product idea is judged ready to enter "formal" development (Frishammar & Florén, 2010). Hence, the fuzzy front end starts with a firm having an idea for a new product and ends with the firm deciding to launch a formal development project or, alternatively, decides not to launch such a project (Frishammar & Florén, 2010).

The so-called fuzzy front end is inherently fuzzy because it is a crossroads where complex information processing, a broad range of tacit knowledge, conflicting organizational pressures including cross-functional inputs, considerable uncertainty, and high stakes must meet (Khurana & Rosenthal, 1998). Followed by formal development towards commercialization, front-end innovation is the first and most important stage of the innovation process since the most critical decisions associated with new product success occur during this stage (Mohan et al., 2016).

Many different front-end innovation processes can be found in the literature. Some are clearly designed to generate a final output that is input into formal development in a traditional waterfall type of new product development process (Cooper, 2015), while some are designed to deliver a minimum viable product that can be validated with customers and then iteratively further refined (Ries, 2011). Front-end innovation processes in literature are typically of two different types; one where the innovation team is guided through stages and sometimes gates, step-by-step, linearly in a particular order, and one where the team instead moves between different modes, in any order they find necessary.

Examples of stage-based front-end innovation processes are:

- TRIZ (Altshuller & Shulyak, 1996),
- The idea to launch stage-gate process (Cooper, 2008),
- The innovation funnel (Wheelwright & Clark, 1992),
- The innovation process (Tidd & Bessant, 2021).

Examples of mode-based front-end innovation processes are:

- Design Thinking (Auernhammer & Roth, 2021),
- Business Model Canvas (Osterwalder & Pigneur, 2010),
- Lean Startup process (Ries, 2010),
- Four lenses of innovation (Gibson, 2010).

The front-end innovation processes are all designed to guide an innovation team from formulating an initial problem or opportunity to one or several initially proven conceptual solutions (Pereira et al., 2017). Both types of processes can be iterative, while stage-based processes have one direction/order.

2.2.3. Exploration as a journey

The characteristics of exploration work can be described as a journey starting out with an initial inquiry or problem statement. This journey can be explained by using the Double Diamond model (British Design Council, 2004), see Figure 6. The starting point is an initial problem statement, and the endpoint is a solution. The journey involves divergence, which can be seen as the expansion of the possibilities space, and convergence, which can be seen as closing the space, making selections and decisions.

During divergence, the possibility space expands as team members ask generative questions, and during convergence, teams reduce the space and make choices through deep reasoning questions (Eris, 2002). Between the divergence and the convergence, there is a transition from expansion to reduction.

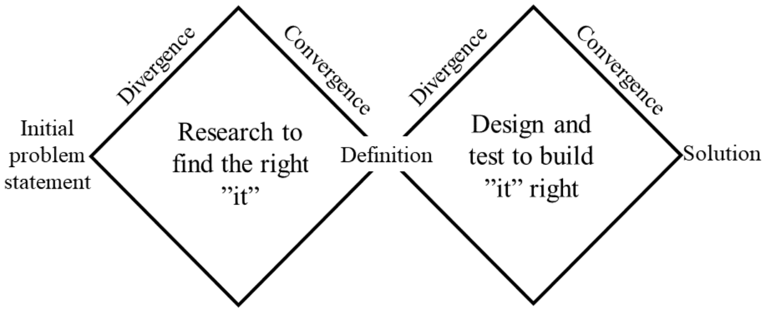


Figure 6. The double diamond model adapted from the British Design Council (2004), with Savoia's (2019) "building the right it" and then "building it right".

One commonly used approach for exploration journeys is Design Thinking, see Figure 7. Design Thinking is evolved from Engineering Design and builds on design focus, human-centeredness, need-finding, and creativity (Patnaik & Becker, 1999; Camacho, 2016; Auernhammer & Roth, 2021). Skogstad & Leifer (2011) suggest that design thinking is the natural method to navigate unknown waters, find and push the boundaries of the possible, and iterate and create innovation. It is applicable in engineering to create a fabricated material with new properties and in management to devise an incentive system that rewards creative thinking. The aim of design thinking is to bring together as many as possible diverse experiences and perspectives in respect to a possible problem situation, which potentially generate breakthrough innovations (Lewrick et al., 2018). Design Thinking seeks to generate innovation from the intersection of what is desirable from a human point of view with what is technologically feasible and economically viable, see Figure 8.

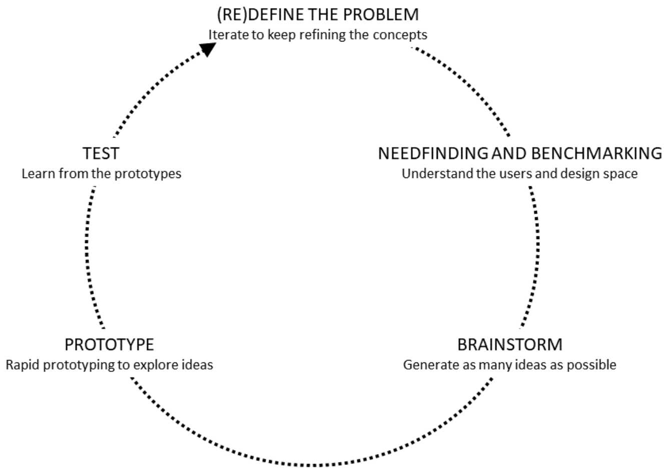


Figure 7. The Design Thinking process visualized, adapted from Stanford University, ME310 course.

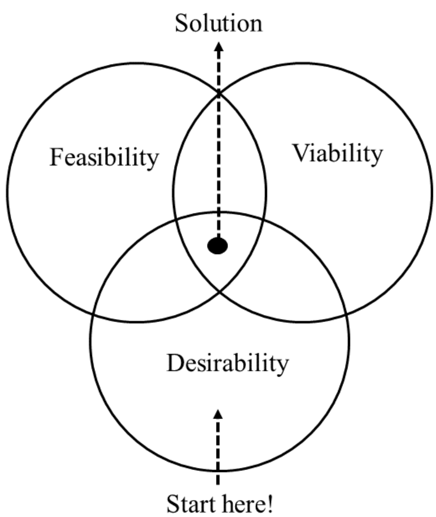


Figure 8. Design Thinking, adapted from IDEO, 2015.

The iterative design thinking approach fits well when the problems to solve are open-ended, systemic, complex, or even wicked (Rittel & Webber, 1973). Buchanan (1992) describes how design thinking can lead to breakthrough innovation because imagined solutions that first are impossible to realize, later, when technology or other external development enables them to be created, rapidly can be brought to customers because the solution is already imagined. Design thinking is not directed toward a technological "quick fix" in existing hardware but toward new integration of signs, things, actions, and environments that address the needs and values of humans (Buchanan, 1992).

Over the years, the concept of design thinking has evolved. Still, a consistent core of design thinking as a cognitive process, creative practice, organizational routine, and design culture, with emphasis on finding profound needs and problems and translating them into a tangible design, creating value for people has remained (Auernhammer & Roth, 2021).

The exploration journey is by Steinert and Leifer (2012) referred to as "Wayfaring", to describe the intellectual challenge of hunting for the next big idea. They suggest that the generative design actions are comparable with hunting, and the optimizing analytical actions are comparable with gathering. The dynamic Hunter-Gatherer Model is a way to explain the shift between the two modes. Wayfaring can be visualized by plotting prototypes as they occur in time (x-axis) and have pivots represented by deviating angles (y-axis) from the previous. A prototyping journey without pivots would be visualized as a linear, horizontal journey. Through wayfaring, the team's understanding of the problem increases, the solution space expands, and more big ideas emerge (Steinert & Leifer, 2012).

When an innovation team on an exploration journey shifts from divergent knowledge building to convergent sharing, validating, and decision-making, they will experience the "groan zone" (Kaner, 2014). The groan zone depicts the time in a group process when "divergent" thinking (the left side, where all ideas are heard), shifts into "convergent" thinking (the right side, where decisions need to be made), see Figure 9.

Kappel (2019) stresses the criticality of the transition from divergent to convergent thinking, emphasizing that it should not be rushed, as it is a pivotal phase that teams must navigate carefully. This phase is where the team's creativity and innovation have the potential to emerge and lead to radical innovation, provided that the team has the freedom to do so and fosters an environment that allows for creativity to flourish. Therefore, recognizing the importance of this shift in thinking can be transformative for the team's innovation process, leading to breakthrough outcomes.

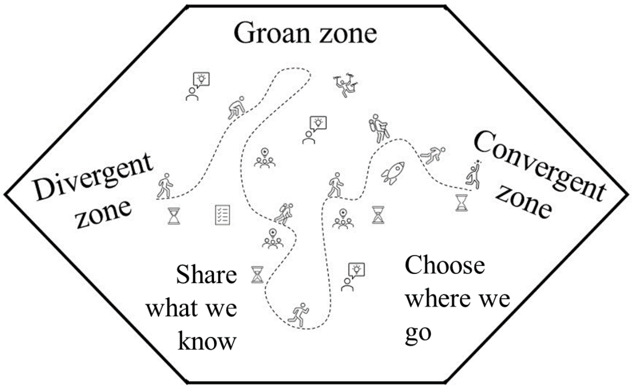


Figure 9. The groan zone, adapted from Kaner (2014).

3.1.1. PSS design

During the exploration process of product-service systems (PSS), it is necessary to zoom out from existing products to create integrated solutions that add value for all stakeholders. However, interdependencies between components can add complexity to the design process (Bertoni & Larsson, 2011; Bertoni et al., 2016). To realize integrated solutions that are truly value-adding for all stakeholders, PSS design requires awareness of customer and stakeholder needs throughout the entire product lifecycle (Isaksson et al., 2009).

The need to integrate several domains, such as product development, service development, and recycling, means that downstream knowledge must be brought into the early phases of the design process. This raises the demand for methods and strategies that support collaboration and cross-disciplinary integration (Ruvald et al., 2021). Prototyping can support this integration throughout the design journey by enhancing communication, learning, and decision-making (Ruvald et al., 2021).

Lugnet et al. (2020) argue that PSSs promote a shift in engineering design from making and selling products to co-creating value with stakeholders. However, this shift can be challenging to achieve, as hidden assumptions about products as standalone manufactured items can drive the design process, resulting in incremental improvements rather than radical innovation (Lugnet et al., 2020).

To support the design of PSS solutions, new tools and approaches are needed (Wall et al., 2020). Lugnet et al. (2020) propose an integrated PSS design model (see Figure 10), which illustrates different system levels on the y-axis and "knowledge silos" on the x-axis. The micro level represents the job that needs to be done and incorporates the upper levels (meta and mesa) into systems innovation activities. In a functional economy, the understanding of a function is more relevant than the need that an existing product satisfies. For example, the need for transportation can be fulfilled by a car or a taxi, but the function of "being there" can also be solved by online participation. The figure shows that the mesa level relates to the context of the job, while the meta level represents the broader societal and environmental contexts that affect the job. By incorporating these levels, the PSS design model encourages designers to think more holistically and consider the larger system in which their solutions operate.

In summary, the design of PSS solutions is a complex process that requires cross-disciplinary collaboration, and an understanding of stakeholder needs throughout the product lifecycle. Achieving a shift from product-based thinking to value co-creation can be challenging, but the proposed integrated PSS design model can help by incorporating micro, mesa, and meta levels into systems innovation activities. New tools and approaches are also needed to support PSS design in practice. By having this approach to PSS design, the different system levels will be considered already from the early development phases. The PSS design approach means that all levels and parts must be considered and sometimes reconsidered to adapt to external factors that are causing changes or the PSS design outcome generating changes to both production and consumption systems. Instead of fulfilling the needs and requirements pointed out by today's customers and current behaviors, this approach might lead to better uptake of transformation toward sustainable solutions or circularity (Lugnet et al., 2020).

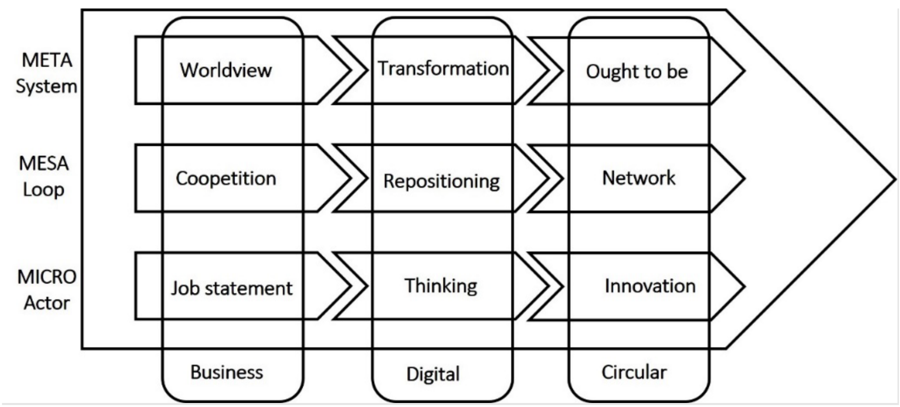


Figure 10. A new discourse for PSS design, adapted from Lugnet et al. (2020).

2.3. Exploration capabilities

Already in 1973, Bell suggested that engineers in the post-industrial world, i.e., the knowledge-based society, need to possess much more than technical expertise in their fields. Dym et al. (2005) suggest that good designers need to have the following list of abilities:

- tolerate ambiguity that shows up in viewing design as inquiry or as an iterative loop of divergent-convergent thinking,
- maintain sight of the big picture by including systems thinking ad systems design,
- handle uncertainty,
- make decisions,
- think as a part of a team in a social process, and
- think and communicate in the several languages of design (verbal, graphical, mathematical etc.).

Samavedham & Ragupathi (2008) suggest that the 21st-century engineers need to work with an understanding of multiple disciplines in collaborative teams that are culturally and philosophically diverse, cultivate complex communication and social skills, and among other things, explain science and technology to a society that is increasingly more doubtful of its impact and intentions despite enjoying the comforts that come with the progress in engineering & technology. Furthermore, Samavedham & Ragupathi (2008) write that engineers must learn to work with ambiguity/uncertainty, with a diversity of disciplines, and with humility regarding their own skills and abilities. Future engineers will need to be technically qualified, flexible, problem solvers, creative and dynamic thinkers, and at the same time collaborators, i.e., they need to be T-shaped individuals.

2.3.1. T-shaped individuals

The concept of T-shaped individuals (Barile et al., 2012), see Figure 11, refers to individuals having deep competence in one (or more) expertise domains (the vertical part of the T) combined with broad, general competence (the horizontal part of the T), in other words, a T-shaped individual is both a specialist and a generalist. In contrast, I-shaped individuals have deep domain expertise albeit with limited abilities to collaborate. According to an interview with Hansen (2010), Tim Brown explained that T-shaped individuals possess two distinct attributes. The vertical stroke of the “T” represents their depth of expertise, enabling them to make valuable contributions to the creative process in various domains, such as industrial design, architecture, social science, business, or mechanical engineering. On the other hand, the horizontal stroke of the "T" represents their ability to collaborate effectively across disciplines, which requires empathy as a crucial trait. Guest (1991) first coined the term T-shaped people when he described "a new breed" of computer managers with skills and knowledge that are both deep and broad.

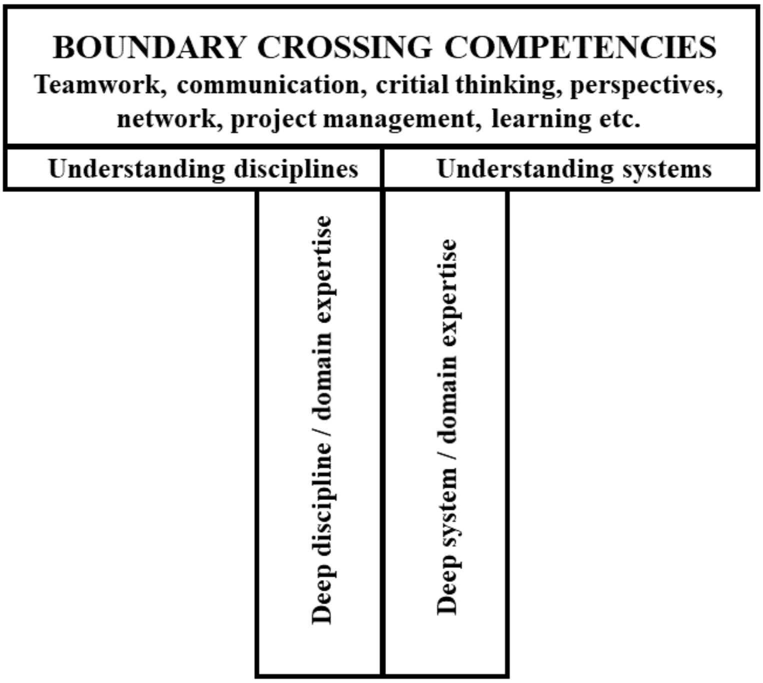


Figure 11: T-shaped people, adapted from Yip (2018).

2.3.2. Innovation team

An innovation team is a team with the purpose of conducting innovation work within an organization (Johnsson, 2016). A multi-functional or multi-disciplinary innovation team is built on the belief that divergences in competencies prevent groupthink and strengthen the team by avoiding internal competition (Johnsson, 2016). Furthermore, Johnsson (2016) identified in an empirical study that the most important enablers of an innovation team's performance are dedication, collaboration, and mindset. Those enablers cannot be provided with external support but instead, need to be fostered and maintained within the team itself. The team can be instructed, trained, and coached by an individual (or a group of people) external to the team (Johnsson, 2016) to develop the necessary enablers.

2.3.3. The knowledge creation process

The knowledge creation process consists, according to Nonaka et al. (2000), of three elements:

- The SECI (Socialization, Externalization, Combination, and Internalization) process,
- The concept of 'ba' (shared context), and
- Knowledge assets (inputs, outputs, and moderator of the knowledge creation process).

Nonaka et al. (2000) describe the SECI process as the process of converting and recreating explicit and tacit knowledge. Through socialization and shared experiences, new tacit knowledge can be created from existing tacit knowledge. Tacit knowledge is hard to capture in the documentation but can be considered a knowledge asset if shared via socialization in the team (Johansson, 2009). Externalization is about articulating tacit knowledge into explicit, which can be documented. Internalization is "learning by doing" by embodying explicit into the tacit.

Experience-based, tacit knowledge is recognized as an important part of product development, though its ambiguousness is evident (Lugnet et al., 2020). Stories about how you, your partners, colleagues, and so forth have dealt with a situation successfully or detrimentally support the creation of an organizational culture but are also a way to share tacit knowledge and make it an organizational knowledge asset (Lugnet et al., 2020). This approach to knowledge sharing is not a habit that comes naturally in large manufacturing incumbents where efficiency is in focus and gates passed on time are a measure of high performance, but necessary to build factual and tacit knowledge together to enable PSS design (Lugnet et al., 2020).

The knowledge creation process is central to an innovation team performing exploration work, and the different modes of building knowledge and sharing knowledge fit well with the divergent, convergent nature of the exploration journey. By intentionally securing time for both knowledge building and knowledge sharing, the innovation team can boost its performance. Additionally, by applying the concept of knowledge maturity and assessing the team's knowledge maturity level (Johansson et al., 2011), any assumptions, ambiguities, and uncertainties can be addressed and managed. The knowledge maturity scale suggested by Johansson et al. (2011) is presented in Table 5.

Table 5: The Knowledge Maturity Scale (Johansson et al., 2011).

KM level	Input	Method	Experience
5: Excellent	Detailed and verified	Tested, standardized, and verified methods that are under continuous review and development	Long verified experience and expertise within area of concerns
4: Good	[redacted]		
3: Acceptable	Available in detailed form, but not verified	Standardized and tested methods have been used	Proven experience and competence within area of concern
2: Dubious	[redacted]		
1: Inferior	Risk of incorrect input	Untried methods have been used (ad-hoc)	Person doing the work is inexperienced (first time)

2.3.4. Social connectedness

An innovation team working with an open-ended, complex problem performs better if social connectedness between all team members is established, which is especially difficult when the team members are not gathered in the same location (Hinds & Kiesler, 2002). Larsson (2007) suggests that social connectedness in global design teams is about Know-Who, defined as the interpersonal relationships that enable people to 'know who knows', to 'know who to ask', and to 'know who to trust". The concept of social connectedness has played a significant role in this research, as the data shows that both team performance and individual experience relate to social connectedness in the teams. Larsson (2007) suggests that know-who principally consists of three dimensions, see Table 6.

Table 6. Social connectedness, described as "Know-Who", adapted from Larsson (2007).

Dimension	Is about knowing who…
Knowledge-of-practice	… knows how the work gets done
Knowledge-of-expertise	… knows how the work should be done, and who to ask who knows that even better
Trust-in-expertise	… has established the relationships and credibility (social capital) in the team to be trusted

As the team learns and thinks together, they utilize their shared knowledge and identify what to do next. Collective social capital as a resource for geographically distributed innovation teams might be neglected due to challenging goals or tight timelines. It is not intuitive for highly motivated individuals to spend time on social aspects when they are under time pressure. Leadership in large manufacturing incumbents rarely endorses a focus on social connectedness.

This chapter provides an overview of the primary theoretical background and core concepts that underpin my research. The primary focus of the research is on innovation teams within large manufacturing incumbents who engage in explorative projects aimed at generating radical or breakthrough innovation. This focus has led to a particular interest in Product-Service System (PSS) solutions and large incumbents' capacity to transition from products to PSS. In addition, the study explores how to support and guide innovation teams conducting explorative projects, as well as the importance of the right surrounding conditions, corporate strategy, culture, and leadership in this transition process.

3. Methodology

3.1. Research context

The research has primarily been conducted within a large manufacturing incumbent's globally distributed R&D function, with corporate sites located in Europe, the Americas, and Asia. The manufacturer has been in operation for several decades and is one of the world's largest heavy vehicle manufacturing incumbents. The study incorporates perspectives from other parts of the organization, including purchasing, sales and marketing, manufacturing, communications, and executive leadership. This research primarily focuses on initiatives undertaken by innovation teams to develop new, innovative conceptual solutions and strengthen the organization's innovation capability. During the research period, I held two executive management positions. From 2009 to 2018, I served as Director of Emerging Technologies and Innovation within a globally dispersed R&D organization. From 2018 to 2020, I served as Director of the Innovation Lab Hub US within an organization responsible for the development of the global corporation's connected services and solutions. Both roles were new for the company, and I was responsible for establishing and operating the functions. In both roles, my team collaborated with internal counterparts and external partners of different types, including large and established suppliers, customers, academic partners involving both researchers and students, startup companies, and public sector actors. As both a Ph.D. student and an industry practitioner with leadership roles, I periodically had to put my research on hold. Journaling notes were instrumental in continuing the research after job focused periods.

3.2. Research methods

This research has been heavily influenced by my practitioner roles, where innovation and exploration as part of my job description have provided opportunities for knowledge-building and research. Due to the characteristics of my research journey, I decided to apply design research methodology, DRM (Blessing & Chakrabarti, 2009). The DRM framework offers a systematic and iterative research approach consisting of four stages with specific focuses and goals that lead to specific outcomes. This is explained in the following subchapter. The case studies conducted in this research utilized an initial design and an interactive, flexible approach throughout the study, as recommended by several researchers (Yin, 2013; Gioia et al., 2013; Eisenhardt, 1989; Maxwell, 2013). The focus of these case studies was on understanding and finding solutions to identified problems, in line with the DRM framework, which requires the researcher to actively seek to understand and address problems. As a practitioner-researcher, I drew inspiration from both action research and participatory action research methodologies (Avison et al., 1999; McTaggart, 1991). Action research typically involves an iterative four-step process: planning, acting, observing, and reflecting (Lewin, 1946; Ghaye et al., 2008). This method requires data collection and analysis, as well as collaboration with others in the specific context and a clear focus. While an action researcher identifies the course of action but does not necessarily engage in those actions (Boga, 2004), a participatory action researcher takes an active part throughout the entire process. Similarly, DRM is a method where the researcher actively engages in understanding the problem, identifying potential solutions, and attempting to solve the problem iteratively. The longitudinal and iterative approach of the different studies, as well as the strong motivation and intention to find and test potential solutions to identified problems, made the DRM framework an effective structure for this research.

3.3. Applied design research methodology

Design Research Methodology, DRM (Blessing & Chakrabarti, 2009), see Figure 12, consists of four stages:

- Research Clarification (RC),
- Descriptive Study I (DS-I),
- Prescriptive Study (PS), and
- Descriptive Study II (DS-II).

The stages are linked in the primary process flow, but many iterations between the different stages can take place. Research Clarification (RC) is where literature studies about the subject of interest and the context help the researcher to find the initial aim and goal of the research and formulate criteria that help measure how successful the research is in corresponding with the goal. The Descriptive Study (DS-I) follows the RC stage and allows the researcher to go deeper into the subject of interest at that time. By identifying the most crucial factors to address, the researcher can combine insights from literature studies with their own observations and empirical data. Based on the combined insights, an initial descriptive study focusing on understanding and describing the existing situation can be conducted through the lenses of the identified criteria. Following the DS-I stage is the Prescriptive Study (PS), where the desired situation is defined. Various scenarios can be described by elaborating on the previously identified crucial factors. With those insights, the researcher can decide a possible way of taking the research object from the existing situation to the desired situation in the most effective way. The selected influential factors become part of the systematic design support resulting from the PS stage and will be tested in the following stage. During the final Descriptive Study II (DS-II), the researcher can investigate the impact of the support developed in the PS stage. Analysis of empirical data provides answers to the research questions defined in the Research Clarification stage, and it is both natural and expected that iterations occur between the different stages.

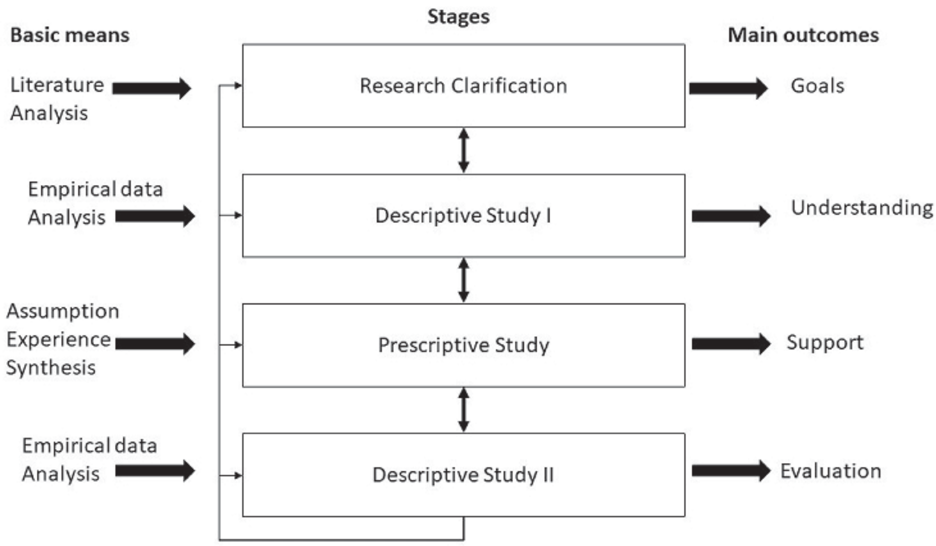


Figure 12. Design Research Methodology (Blessing & Chakrabarti, 2009).

Table 7 (on next page) lists the publications selected as building blocks in this thesis and mapped against the DRM framework. The licentiate thesis is included as a publication despite overlapping with previously published papers. The reason is that the author’s involvement prior to 2016 was not as a Ph.D. student but as an industry practitioner and research partner.

Table 7. Appended papers mapped in the DRM framework.

Paper	Year	Topic	RQ1	RQ2	RQ3	RQ4	RC	DS1	PS	DS2	Main data sources	Implications
A	2014	Innovative capability - what it means and constraints	X	X				X	X		Semi-structured interviews	An integrated approach with an innovation framework, innovation ambassadors, and an online idea sharing platform.
B	2015	Developing and implementing an actionable innovation measurement system	X	X	X			X	X	X	Workshops, survey data, observations and field notes, semi-structured interviews, statistical data	The value of measuring innovation in a large, complex organization and how its implementation through iterations can enhance its effectiveness.
LICENTIATE THESIS	2018	Strengthening innovation capability of a large, mature firm	X	X	X		X	X	X	X	Literature study, semi-structured interviews, observations and field notes, survey data, statistical data from online platform	An integrated approach to innovation, combining an innovation framework, innovation ambassadors, an online idea sharing platform, and data-driven measuring of innovation. Self-organizing innovation teams are also incorporated.
C	2020	How a corporate innovation hub can maximize its value to the corporate investing in it		X	X			X	X	X	Literature studies, semi-structured interviews, observations and field notes, survey data, debrief interviews	Building and leading an innovation team as a community of stars, highlighting the significance of autonomy in a corporate innovation hub. Additionally, the leader's role as a buffer/translator is identified to be crucial.
D	2021	How corporate innovation hubs can mitigate not-invented-here and not-sold-here problems in knowledge transfer	X	X	X			X	X		Literature studies, semi-structured interviews in three waves, workshops	Exploring the "not-invented-here" and "not-sold-here" problems in incumbent firms with Silicon Valley-based corporate innovation hubs, analyzing their causes, consequences, and potential mitigating mechanisms.
E	2021	What makes an innovation team achieve breakthrough innovation even against all odds		X		X		X			Semi-structured interviews, observations and field notes, project related documentation	The success of an innovation team during the COVID-19 pandemic, and is a separate analysis from the longitudinal study presented in Paper F. Specifically, it explores the factors that contributed to the team's impressive achievements.
F	2023	How an innovation team conducting exploration work can be guided to reach its highest potential		X	X		X	X	X		Semi-structured interviews, observations and field notes, project related documentation	Proposes tools for supporting innovation teams in their exploration work. It outlines key factors contributing to successful exploration-based innovation, and offers strategies for encouraging cross-functional collaboration, experimentation, and continuous learning.
G	2023	Identifying why PSS solution concepts get stuck and how to bridge between explore and exploit		X	X	X	X	X	X	X	Semi-structured interviews, observations and field notes, project related documentation, literature studies	Proposes approaches to bridge the gap between exploration and exploitation to enable promising PSS concepts to reach the revenue stage. These approaches include intentional PSS design and process visualization, which serve as tools for innovation engineering and decision-making.

RQ1: How can large manufacturing incumbents strengthen their innovation capability?
RQ2: How can exploration be institutionalized, guided, and led in large manufacturing incumbents?
RQ3: How to bridge exploration and exploitation in large manufacturing incumbents?
RQ4: How might bridging between exploration and exploitation help a large manufacturing incumbent to shift its business orientation from products to product-service systems?

3.4. Data collection and analyses

This research involves case studies that incorporate an initial design, as well as an interactive and flexible approach, throughout the study to test the assumption (Yin, 2013; Gioia et al., 2013; Eisenhardt, 1989; Maxwell, 2013). Case studies are described by Eisenhardt and Graebner (2007) as detailed descriptions of specific instances of a phenomenon that are typically based on various data sources. This research utilizes a range of data sources, including literature reviews, semi-structured interviews, online surveys, workshop results, observations, journaling notes, existing documentation, quantitative data, and informal discussions within the research team, with the selection of data collection methods being dependent on the specific focus and purpose of each case study, for more detailed information on each case study, see corresponding papers. Findings from one case study have been compared and contrasted against other cases or existing theories (Maxwell, 2013; Yin, 2013; Eisenhardt & Graebner, 2007). The data analyses followed the recommendations of Blessing and Chakrabarti (2009) and Gioia et al. (2013). After data collection, we processed and analyzed the data. Typically, we first conducted semi-structured interviews to determine whether there was a typical pattern, and once patterns emerged, we built on this pattern to conduct more in-depth semi-structured interviews, to design online surveys, and to utilize journaling notes or informal discussions as another relevant data source. Given that almost all of the data collected were qualitative, we applied triangulation of data (Robson et al., 2020) to gain a comprehensive understanding of the phenomenon being studied.

3.4.1. Literature reviews

To design the case studies, extensive literature reviews were conducted using the SCOPUS database and the Web of Science platform. Initial publications were identified through a forward snowballing technique (Wohlin, 2014), which led to further relevant readings based on references cited by the authors. Table 8 presents the search criteria used for SCOPUS and the number of conference papers and articles identified in the search results to illustrate how the initial publications were selected.

Table 8. SCOPUS search results.

SCOPUS advanced query	Papers	Articles
ABS (organizational OR organization) AND ABS (ambidextrous OR ambidexterity) AND ALL (product A ND (manufacturing OR manufacturer)) AND ALL (incumbent AND (strategic OR strategy)) AND ABS (innovation) AND NOT ALL (regional) AND NOT ALL (local)	1	19
ABS (radical OR breakthrough OR disruptive OR explorative) AND ABS (innovation AND engineering) AND ALL (manufacturing) AND ALL (incumbent OR (large AND mature) AND (firm OR company OR corporate OR enterprise))	0	9
ABS (innovation OR innovative) AND ABS (skills OR capability OR capabilities) AND ABS (industry OR production OR products OR manufacturing) AND ABS (large AND mature AND company OR firm OR corporation OR incumbent OR enterprise) AND ABS (business)	5	3
KEY (innovation OR innovative AND team) AND KEY (engineer OR engineering) AND ABS (project OR process OR method OR methodology OR approach OR paradigm) AND ABS (explore OR exploration OR explorative)	31	13
ALL (product AND development) AND ALL (engineering AND manufacturing OR production) AND ALL (large AND mature AND company OR firm OR corporation OR incumbent OR enterprise OR corporate) AND ABS (radical OR breakthrough OR disruptive OR disruption) AND ALL (future-proof OR future-proofing OR competitive OR competitiveness) AND ABS (innovation) AND ALL (strategy AND strategies) AND ALL (organization AND team)	3	33
ABS (engineering AND design) AND ALL (product AND development AND prototyping) AND ALL (product AND service AND system OR pss) AND ALL (team OR teams) AND ALL (radical OR breakthrough OR disruptive OR disruption) AND ABS (innovation) AND ALL (knowledge AND creation OR building OR maturing OR shared) AND ALL (performance)	3	1
KEY (innovation AND strategy AND management) AND ABS (manufacturing) AND ABS (engineering OR r&d OR (product AND development)) AND ABS (incumbent OR enterprise OR company OR corporation OR (large AND mature AND firm)) AND ABS (competitiveness OR renewal OR disruption OR futureproofing) AND NOT ABS (regional AND region AND policy) AND ALL (management)	7	2

3.4.2. Semi-structured interviews

The primary source of data in this research has been semi-structured interviews, which involved one-on-one conversations with participants using a combination of closed- and open-ended questions, supplemented by follow-up "why" or "how" questions (Adams, 2015). The purpose of these interviews was to gain an understanding of the practitioners' perspectives on the problem and explore potential solutions. The interviews were designed with open-ended core questions (Yin, 2013), and follow-up questions based on respondents' answers. When the analysis of the interviews revealed typical patterns or clear deviations, a secondary interview was conducted with a more focused set of questions to gain a deeper understanding of the phenomenon (Yin, 2013). The patterns that emerged from the semi-structured interviews also served as a basis for designing online surveys (when applicable) to test whether the identified patterns were generalizable among a broader group of respondents. The initial set of interviews involved walking the participants through their experiences and eliciting their thoughts on their team's performance. The research team cross-checked the participants' views on their performance against the supporting cohort's notes to ensure accuracy. In the case study presented in papers E and F for example, the research team analyzed the data from the first six interviews and identified a typical pattern for the most high-performing teams.

This pattern then served as a guide when structuring subsequent semi-structured interviews and online surveys. A flowchart depicting the interview and survey process is provided in Figure 13.

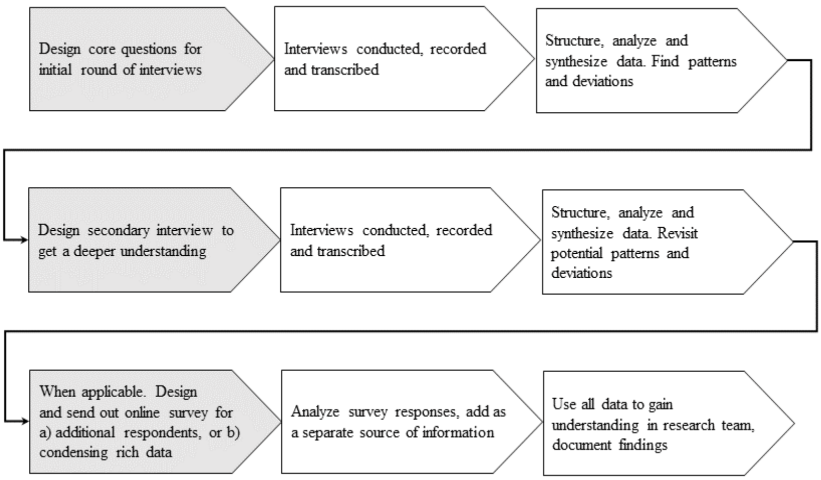


Figure 13. Data collection through interviews

3.4.3. Online surveys

The use of online surveys complemented other data sources and served to confirm or challenge insights gained from semi-structured interviews (Edmondson & McManus, 2007). The surveys were divided into two parts, with the first consisting of rating questions and the second containing open-ended questions. The survey results provided data that could be compared against the identified pattern as well as free text responses that provided additional information. In the study of student teams, the online survey was designed based on insights gained from semi-structured interviews, while the study of corporate innovation hub leaders used a list of desired conditions identified through both literature review and interviews. In the innovation metrics case study, an online survey was sent to all employees within the globally distributed R&D organization, providing rich data for the research.

Table 9 presents the categories of respondents against the papers. Industry respondents included my colleagues at the large manufacturing incumbent, some of whom worked in the same part of the company, and others from different parts of the company. Other industry respondents were leaders at other large manufacturing incumbents, within or outside of the same industry. Master-level students who were respondents in this research included final year M.Sc. students at Blekinge Institute of Technology, graduate students at Stanford University, and alumni students who had taken the same course. Academic professional respondents were all part of the supporting cohort of the student teams, employees either at Blekinge Institute of Technology or at Stanford University.

Table 9. Categories of respondents mapped against papers.

Respondent category	Type of data collection	Paper
Industry	Semi-structured interviews, online survey	A, B, C, D, G
Master level and alum students	Semi-structured interviews, online survey	E, F
Academia	Semi-structured interviews	E, F

3.1.1. Workshops

This research has involved workshops, which are collaborative meetings with clear structure and intent that involve multiple participants. We have used different workshop formats depending on the situation and objective, with the main approaches being the world café method (Löhr et al., 2020) and the MOVE method (Carleton et al., 2011). In some studies, we used workshops to acquire knowledge or find solutions. For example, in the case study where we implemented innovation metrics according to the MINT framework (Nilsson et al., 2010), we used workshops to identify the company specific metrics.

These workshops involved employees from different organizational functions and global sites and were performed iteratively. Involving participants in this broad manner helped ensure that the selected metrics were meaningful to them and that they accepted the implementation process, which included development work. In another study, we used a workshop to test and adjust an initial framework with a smaller group of interview respondents before improving and finalizing it. Also, in a multiple case study addressing the challenge of large manufacturing incumbents shifting from offering product to PSS solutions, we conducted workshops both with external partners and different internal stakeholders to understand the problems the customers wanted to have solved and the different stakeholders´ envisioned wanted solutions. While these workshops were not designed for research, we used the output documentation as data for our study.

Throughout this research, workshops has been found to be instrumental in clarifying the research aim and in designing the studies. The go-to framework for workshops has been the MOVE framework (Carleton et al., 2011), which is based on four dimensions of team innovation in an iterative, non-linear process, see Figure 14.

Figure 14. The MOVE framework, by Carleton et al. (2011).

Throughout this project, I have blended my academic research with my industrial practice, requiring a shift between my different roles. The MOVE framework (Carleton et al., 2011) has been instrumental to facilitate this transition and enable effective research-related workshops that were distinctly separated from my day-to-day work.

3.1.2. Data gathered from existing documents

The different types of existing documents that have been utilized as sources of information in this research are student project-related documents and internal company documents related to projects, process, and organization. In Table 10, the various types of documentation are mapped against the papers presented in this thesis.

Table 10. Documentation mapped against papers.

Paper	Existing documents
A	Strategy documents addressing technology development, Customer satisfaction surveys and competitor benchmarking reports, Process descriptions and procedural guidelines, Success metrics and key performance indicators, Data from the company's idea sharing online platform, Job and Role descriptions, Advanced engineering project documentation, Executive management verbal and written communication, Resource allocation and R&D portfolio balance.
B	Data from the company's idea sharing online platform, Data from a company internal online survey (iCompass) sent out to all R&D employees regularly, Data from the financial management system regarding budget and resource allocation, and product lifecycle related data regarding number of innovative features in ongoing projects and innovative features launched to customers, Other data used in this study was number of innovation disclosure and filed patents, and other actors communications about the company and its innovations / innovativeness.
C, D	None
E, F	Course syllabus, weekly missions, instructions from teaching team, Project prompt, Communication on team's chat channel (Slack) and shared team documentation on server (Google drive), which include reports, shared information from need-finding and prototype builds and tests, deliverables, manufacturing plans, video clips, photos etc.
G	Project related documents, from the initial opportunity description to project scope to project progress reports and decisions and a final integrated solution description. This includes technical specification and simulation models when existing, need-finding documentation, internal and external ideation workshop designs and outcomes, conceptual ideas and different prototypes, result reports from tested prototypes, and project team logs when existing.

3.1.3. Quantitative data

This study incorporates limited quantitative data, specifically metrics related to the innovation metrics initiative. These metrics include R&D portfolio balancing, innovation process throughput, the adoption rate of the idea-sharing platform, invention disclosures, and filed patents as IPR-related metrics, as well as the monetary value and number of innovations that reached the market. The company's internal reporting was used to collect this data.

3.1.4. Journaling notes and informal communication

Since May 2018, journaling notes have played a crucial role in my research, facilitating easy integration into the research process due to the light structure. Given the varying workload in a leading practitioner role (head of division / director), my research was temporarily paused during busy periods. The journaling notes served as an anchor, allowing for a seamless return to the research after extended hiatuses by reestablishing focus and areas of interest. For ease of use, two separate notebooks were utilized: one for operational work tracking actions and follow-ups in the daily work (i.e., a bullet journal), and another for reflections and free writing related to the research questions. The latter was structured around three levels:

- Innovation team level, focusing on team dynamics, individual behaviors, skills, learning experiences, and team performance,
- First level external to the team, representing the support, guidance, or leadership provided or not provided to the team, with a focus on the impact on team dynamics and team performance,
- Second level external to the team, representing other teams interacting with the studied team, interactions, and exchanges with the larger organization, executive leadership attitudes, communication, and decisions.

Although not sufficient as data sources on their own, the journaling notes have been invaluable as documentation of the research process, aiding in organizing and revisiting areas of interest requiring further investigation. Informal communication among the research team, including academic supervisors and Ph.D. student peers, has played an integral role in this research. These conversations have often proven crucial in development phases, where the academic research perspective was needed to design the development process and research study as separate activities. Additionally, these conversations facilitated reflective and retrospective lenses during the design and planning stages. They were especially crucial in the student team studies, where they provided valuable information about the cohort's differing observations, concerns, disagreements, and disconnects.

Additionally, it is important to acknowledge the value of having academic Ph.D. students as research peers, while I was a part-time (or moonlight) industrial Ph.D. student who had to balance employer expectations and the researcher role. The diverse foci and varying depths of knowledge, combined with a willingness to help each other, to share perspectives and ideas, and to improve performance in both directions, have been very helpful.

4. Summaries of the appended papers

4.1. Paper A. Becoming an innovative company: Assessing an organization's innovation capability from the perspective of a team

This paper is focused on understanding how R&D employees in a large manufacturing incumbent perceive innovation capability within their work environment. The findings presented in this paper relate to the first research question regarding how large manufacturing incumbents can build innovation capability. The Becoming an Innovative Company paper was co-authored with André Benaim, Tobias Larsson, and Andreas Larsson as a contribution to the 15th International CINet Conference, Budapest, Hungary, in September 2014.

4.1.1. Summary

The purpose of this study was to understand how employees involved in an initiative to strengthen a large manufacturing incumbent's innovation capability perceived the company's existing capabilities and their perspectives on innovation capability, including company-specific challenges and opportunities. The initiative started in April 2009 when a new department named Emerging Technologies was launched, an entity within the R&D organization's Advanced Engineering function. The team was given the responsibility to explore new technologies and strengthen the company's innovation capability. After literature studies, internal and external interviews, and discussions with academic partners, the team concluded that there are nine essential factors that must be actively managed if a large and globally distributed company wants to become more innovative. In February 2010, these nine factors formed the company's framework called "The Innovation Model" and were approved by the president of the company.

Table 11. The company's innovation model with its nine essential factors.

Innovative culture: Behaviors, attitudes, shared beliefs, values	**Sharing ideas:** A collaborative approach to sharing and building on each other's ideas	**Future goal:** An envisioned end-state providing a direction to strive for
Clear innovation process: A clear, simple, agile, and transparent process for ideas	**User / customer oriented:** A need-based innovation approach stays relevant longer	**Clear leadership:** Strong executive leadership protecting, promoting, and inviting all employees to contribute
Committed management: Leaders throughout the hierarchy needs to not only tolerate, but also contribute to the right conditions and encourage employees to engage	**Inspiring working environment:** A physical and virtual employee experience that reinforces creativity, interaction, experimentation, and co-creation	**Time for ideas:** Having enough slack for need finding, free thinking, creative problem solving and experimentation

A global network of innovation ambassadors, or iCoaches, had also been established. This was a part-time role to support and coach locally, to network and share knowledge globally, and to participate in the development of the company's innovation capability. A role that was crucial in a globally dispersed R&D function with 11 different sites. In this study, we wanted to understand how innovation capability was perceived within the existing working environment. Semi-structured interviews were designed around six components that Nilsson et al. (2010) suggest constitute innovation capability. The components are 1) strategic innovation processes, 2) input (in the form of resources and tasks), 3) output (in the form of deliverables, results, and effects), 4) feedback (in the form of measurements and evaluations), 5) internal context (in the form of organizational surroundings), and 6) external context (in the form of users, customers, and stakeholders). Nine semi-structured interviews with respondents that were either in the core team or held an iCoach role were conducted and analyzed. The study provided insights into the challenge of "inserting" innovation capability into an efficiency-oriented, throughput-focused organization, where gates passed on time was a key performance metric. Middle managers could appreciate the importance of innovation but were at the same time constrained by key performance metrics, tight deadlines in prioritized projects, challenging budget frames, and continuous pressure to reduce product and project costs. Many engineers were assigned tasks in multiple time-constrained delivery projects, and the free time for innovative work was mostly dependent on the employee's own motivation and willingness to use their free (off work) time. For a middle manager, far away from the headquarters, there were very few reasons to support innovation initiatives and encourage team members to explore and innovate. At the time of this study, the company was new to the idea of strengthening innovation capability. Some engineers felt that they were allowed, some even felt encouraged to perform activities like exploring customer needs and testing ideas, and others felt that while it might be tolerated, it is not appreciated. Many engineers described that if they wanted to be innovative, this work needed to be put on top of everything else, mostly time-constrained, prioritized tasks. Middle management respondents described how they did what they felt was reasonable to support the initiative; some were frustrated because what executive leadership had stated was unrealistic and even disrespectful when they were struggling with scarce resources and time pressure. At the time of this paper, quality was a clear top priority, and some said innovation is the opposite of quality.

The clear strategic intent from executive leadership, the Innovation Model with nine factors, clear organizational ownership, a core team, and iCoaches available on all R&D sites generated sufficient initial motivation for the team to carry on despite some major concerns. One major concern and problematic challenge was the disconnect between the ambition on the executive leadership level and the daily work of the broader organization. One solution was to develop and launch an online communication platform, Interact, which allowed for clear, inclusive, and transparent information for everyone, initially only the R&D function, then all company employees. It was observed that the different sites managed the initiative in ways that suited their cultures and conditions best. It was concluded that these differences were necessary and that the work to strengthen a large manufacturing incumbent's innovation capability is complex and multi-layered.

4.1.2. Relation to thesis

This paper provided an early understanding of the nature and experience of organizational inertia in a large manufacturing incumbent that makes a strategic decision to become more innovative. In this paper some of the identified core components of building innovation capability in large manufacturing incumbents are first described, being the innovation model with nine factors and the global network of innovation coaches.

4.1.3. Author's contribution

The study was performed with a combined inside / outside perspective enabled by close collaboration between academia and the company. As the industrial practitioner, I was responsible for the entire innovation-strengthening initiative, from developing a proposal based on the executive management team's request to designing the solution, implementing it, and continuing the development. In this study, it was possible for the research team to combine an in-depth understanding of the company's conditions and dynamics with the academic research perspective. The study provided early insights into the relation and disconnect between the innovation aspiration and the daily deliverables in a large incumbent's R&D organization. The research team compared this case to other studies and, early on, identified the company's "do not disturb" approach as a potential weakness. The "do not disturb" approach refers to the way the initiative was introduced and adopted in the larger organization, with a clear and strong commitment in the way top leadership communicated, but that commitment was not cascaded down through the layers and was therefore considered to be optional and rather a distraction than a responsibility by many middle managers and engineers. By being responsible for the initiative at the company, insights from the study led to adjustments in the continued work, and observations, discussions, and other contextual implications could be captured for the continued corporate initiative and the research. The combined insights from informal dialogues and semi-structured interviews gave broad and deep insights into the direct and indirect effects on the global organization. Also, this paper's research is based on observations and insights from an experimental implementation of an online tool for reporting metrics, with room for iterative improvements.

4.2. Paper B. The implementation of innovation metrics: A case study

This paper examines the initial implementation of innovation metrics at a large manufacturing incumbent. A framework called MINT, Measure Innovation Metrics in Teams (Nilsson et al., 2010), was selected as the most suitable alternative because of its systemic approach, where a combination of qualitative and quantitative data can provide holistic information about the progress. In parallel with the implementation, the authors performed a case study where Design Research Methodology (Blessing & Chakrabarti, 2009) was applied, including a descriptive and a prescriptive stage. The findings presented in this paper relate to my first, second, and third research questions regarding building innovation capability, decoding, guiding and leading exploration, and bridging between exploration and exploitation. The implementation of the Innovation Metrics paper was co-authored with André Benaim, Tobias Larsson, and Andreas Larsson as a contribution to the 20th International Conference on Engineering Design (ICED 15), Milan, Italy, in August 2014.

4.2.1. Summary

Due to challenges with innovation capability development, resource prioritization, and strategic alignment across globally dispersed sites and managerial layers it was suggested to the executive leadership that an innovation measurement method should be implemented. The core team leading the innovation capability initiative experienced lack of interest and support from line management and most functional management teams. It was also noticed that many employees that had engaged in the initiative were frustrated over how leadership didn't see their contribution to innovation as a priority. The executive management team did not feel they could follow the progress, and the initiative's effectiveness was questioned. The suggestion was approved, and the core team was given the responsibility to select method and implement it across all R&D sites in the company.

With the aspiration to integrate exploration with exploitation, finding ways to assess the current state, track progress, identify needs for corrective action, and communicate the work comprehensively is necessary. The company has long experience following up quantitative key performance indicators (KPIs), and some experience of goal setting systems of objectives and key results (OKRs) as well as employee engagement assessments, but the multi-layered and complex work with the strengthening of innovation capability requires a system of metrics, and the MINT framework (Nilsson et al., 2010) provided that. Originally designed for temporal innovation teams, an integrated approach was taken with metrics related to a global process, local cultures and climates, and other more consistent indicators with a clear connection to mandatory processes and guidelines and local leadership. The drawback of this approach was that the indicators did not fit every team perfectly. Still, the consistency across teams and sites was prioritized as this initiative was a way of driving change. The implementation was performed iteratively, with regular status reporting to the executive management team, which understood and accepted the integrated approach, despite its ambiguous nature. Still, clearly expressing that the wanted outcome is increased competitiveness and profit.

The four uses of the indicators were:

- To implement an innovation strategy to promote behavior.
- To diagnose - monitor trends.
- To learn by experimenting with the metric system.
- To reflect on practice.

The innovation measurement system contributed to strengthened innovation capability. With shared data showing progress per site and per function, comparisons, experience exchange, knowledge sharing, and corrective actions were more engaging and prioritized. The awareness created by a simple visual triggered conversation about innovation and ambidexterity. Initially, some conversations questioned the accuracy of measuring progress in the MINT framework. Still, as the organization matured, opinions converged towards a global consensus that it is better to measure something, even if not perfect, than wait for perfection and have nothing. The company came from a past where filed patents had been the only innovation metric, and it was obvious that the new system provided much more value than one numeric KPI. This case study provided an understanding of how powerful shared mental models can be and how innovation measurement drives improvement, despite the multi-layered complexity it implies.

4.2.2. Relation to thesis

This paper contributes to the thesis by providing insight into the importance of measuring innovation in a way that corresponds with the multilayered complexity and the inescapable interdependencies in globally dispersed matrix organizations. Due to the company's long history of incremental innovation, i.e., exploiting existing products, organizational inertia makes the innovation capability-building initiative challenging. The innovation measurement system was implemented 5+ years into the work and rapidly shifted the attitudes towards the initiative and the speed of change.

4.2.3. Author's contribution

As the main responsible at the company, I designed and performed company-internal, cross-departmental workshops with the main author. We gathered a gross list of potential company-specific metrics, selected a set of metrics, and iterated the set by involving management teams and key individuals. Once the first version of a final set was concluded, I led the global implementation at the company. Through semi-structured interviews and online surveys, we collected context-specific research data. This study was inspired by participatory action research methodology. Within the research team, we could balance my company-specific insights with theories and compare them with other contexts from which the academic team had experience. A practitioner's involvement in this case study was essential to mitigate confusion and misinterpretation. A complex organizational structure, a globally dispersed workforce, and continuous change at the company (besides the innovation-strengthening initiative) required internal adaptability and anchoring.

4.3. Paper C. Unlocking the full value of a corporate innovation hub

This paper summarizes a study performed during the time I was responsible for designing, establishing, and heading up a corporate innovation hub (CIH) in Silicon Valley as part of the corporate Connected Solutions Innovation Lab. In this descriptive and prescriptive study, the research team compared large manufacturing incumbents' CIHs in Silicon Valley regarding purpose and expectations, organizational and procedural structures, local operating conditions and cultures, and relations to and interactions with the corporate headquarters. The findings presented in this paper respond to my second and third research questions; how to institutionalize, guide and lead exploration and how to bridge between exploration and exploitation. The Unlocking the full value of a corporate innovation hub paper was co-authored with Tobias Larsson, Andreas Larsson, and Christian Johansson Askling as a contribution to the ISPIM Connects Global 2020 event in December 2020.

4.3.1. Summary

By investigating differences and similarities between large manufacturing incumbents' Corporate Innovation Hubs, CIHs, in Silicon Valley, we wanted to understand how to maximize the value of a CIH. During the time of the study, I was based in Silicon Valley, reported to an executive leader based at the corporate headquarters, and during a two-year period, we took a CIH from an initial conceptual idea to a fully operational corporate foothold, consisting of both a mobility-oriented innovation community in a shared office space and a small, multi-disciplinary innovation team with the responsibility to explore possibilities and generate conceptual digital solutions that the customer-facing organization would be willing to adopt.

The CIHs were established based on different combinations of intentions and expectations, but all with exploration together with external partners as one core responsibility. The interviewed CIH leaders similarly described their roles as being representatives of their companies in the ecosystem, protective buffers for their local teams, and translators that can bridge between their local teams and the larger organization. All CIHs' team constellations were multidisciplinary and aimed at utilizing diversity as a strength; the psychological safety within the teams and the importance of embracing failure as a learning experience without judgments were described by all respondents. It was also observed that the provided value from the CIHs to their corporates depended on:

- The level of autonomy and the freedom to collaborate with external partners in agile and iterative ways,
- The reporting level for the leader of the CIH,
- The relationship with and the frequency of interaction with the C-level executive management team,
- The focus on knowledge building and exploration of relevant performance metrics rather than exploitation-optimized resource planning and detailed financial follow-up.

All respondents in this study experienced internal friction, in some cases antagonism, related to the differences in mindsets, ways of working, and expectations from the local talents. The lack of curiosity and understanding from the larger organization burdened the CIH leaders despite strong commitment to their mission, loyalty towards their employer, and appreciation for the opportunity they were given. This study concluded that CIHs could be more successful if the presence in Silicon Valley is managed more proactively, consciously, and systematically. Insights from this study can help large manufacturing incumbents provide the best possible conditions for their CIHs and unlock the full value of the investment.

4.3.2. Relation to thesis

This paper contributes to the thesis by understanding how an exploration-oriented innovation team within a large manufacturing incumbent can be better implemented and managed through a more proactive and thorough planning and design approach. This study mainly covers the perspective of the individuals given the task of heading up the CIHs and provides an important understanding of the buffer role, i.e., the role of the leader as both shielding and translating between the local team and the “mothership”.

4.3.3. Author’s contribution

The study was performed from August 2018 to August 2020. Initially, data was collected as journaling notes, without a pre-designed structure, with both a focus on learning from other heads of CIHs and a focus on documenting the development I was responsible for. There is a mindset that Silicon Valley is known for; it is called the "pay-it-forward" mindset, and it manifested itself in the way all respondents shared their experiences, learnings, mistakes, and networks generously with me. From the initial contact, all respondents were eager to support my work in building up the CIH and this study. During the Covid-19 lockdown, time was available for both the respondents and me so that I could design and perform semi-structured interviews, followed by an online survey and documentation of all collected data so that the rest of the research team could take part in analyzing data, discuss, and conclude findings.

4.4. Paper D. Mitigating not-invented-here and not-sold-here problems: The role of corporate innovation hubs

This paper investigates how corporate innovation hubs (CIH) can avoid common problems with not-invented-here and not-sold-here problems. Five CIHs were studied through interviews with respondents representing the CIH, external partners, and the corporate headquarters. The research team identified during the study that two main problems need to be mitigated: the Not-Invented-Here (NIH) problem and the Not-Sold-Here (NSH) problem. This paper responds to the second and third research questions regarding decoding, guiding, and leading exploration and bridging between exploration and exploitation. The Mitigating not-invented-here and not-sold-here problems paper was co-authored with Marie Amann, Gabriel Granström, and Johan Frishammar and was published in Technovation, Volume 111, March 2022.

4.4.1. Summary

The five CIHs studied in this paper were seen as independent and boundary-spanning corporate units set up outside ordinary business structures with the mission of scouting for new ideas, concepts, and technologies. An inductive research method allowed that theory and understanding of the topic could emerge progressively. In this study, the research team built on existing knowledge about the causes of NIH problems and NSH problems and connected the two in a framework where mechanisms to mitigate the problems can be considered simultaneously. By having the causes, mitigation mechanisms, and consequences, if not managed, in the same visual framework, mutual understanding within the corporation and with external partners can be enabled. In the study, we explored the causes of NIH and NSH problems, the consequences those problems might lead to, and what mitigation mechanisms might be useful. Semi-structured interviews in three waves provided a deep understanding of causes, consequences, potential ways to mitigate the problems, and correlations between those. It was concluded that NIH problems could be mitigated by 1) translating the relevance of ideas and 2) creating mutual ownership. For NSH problems, the two suggested mitigation mechanisms are suggested to be 1) mutual confidentiality understanding and 2) the use of appropriate safeguarding. Because of the substantial investment and significant risk of establishing a new CIH in Silicon Valley, this study was an important component in designing the CIH. The most important outcome of the study is the framework that helps corporate people to understand how to deal with external partnership opportunities.

4.4.2. Relation to thesis

This paper is selected to be part of this thesis because although it particularly addresses problems large manufacturing incumbents experience with their corporate innovation hubs, these problems also address the disconnect between exploration and exploitation. The not-invented-here and not-sold-here problems were explored, and ways to mitigate them were identified. The findings are relevant for large manufacturing incumbents operating corporate innovation hubs or just separating exploration-oriented and exploitation-oriented parts of the organization. While the initial intention of the study was focused on a newly established hub, more mature CIHs were also included. Thus, insights presented in this paper have relevance beyond planning and establishing corporate innovation hubs as well as addressing the disconnect between exploration and exploitation in large manufacturing incumbents.

4.4.3. Author's contribution

The paper summarizes Marie Amann's and Gabriel Granström's M.Sc. thesis, where I participated as their industry supervisor, and Johan Frishammar participated as their academic supervisor. I was deeply involved in designing the study with the aim of identifying ways to make a corporate innovation hub successful. The study involved respondents from Silicon Valley and the different corporates' global headquarters. My main contribution in this study was during the initial design of the study, in the data analysis phase, and in the writing of this paper.

4.5. Paper E. How Covid-19 enabled a global student design team to achieve breakthrough innovation

This paper covers a study of an innovation team consisting of mechanical engineering students at two universities throughout their exploration journey. This team achieved breakthrough innovation when taking a full-year graduate student course, despite experiencing the disruption of the Covid-19 pandemic. This paper responds to my second research question regarding decoding, guiding, and leading exploration. This paper was co-authored with Christian Johansson Askling, Martin Frank, Andreas Larsson, Tobias Larsson, and Larry Leifer as a contribution to the International Conference on Engineering Design (ICED21), Gothenburg, Sweden, in August 2021.

4.5.1. Summary

This case study was part of a larger study spanning several years and involving several teams, but because of its uniqueness of being the first Covid-19 year, it became a published paper. A team of M.Sc. graduate students, taking a problem-based learning course, which is a capstone course spanning over a full school year, were given a project prompt focusing on "the future of the waste industry," with the addendum of the corporate's future vision of "triple zero" vision (zero accidents, zero emissions, zero unplanned stops). As the team experienced the exploration journey, first by exploring the problem space, then by exploring the solution space, they demonstrated a high level of social connectedness. They were able to manage challenging passages through their journey. The team preserved ambiguity, partly intentionally because it is emphasized in the course and partly because they struggled to find their "it" (Savoia, 2019), which means many of their potential solutions were good. Still, no solution felt like the most meaningful one. Thanks to a high level of social connectedness established when they met and worked together before Covid-19 shut down academic institutions and large parts of society, they could accept and embrace the ambiguous nature of exploration. They also demonstrated how to work as a team who has no hierarchy but is a community of stars. The team struggled through the groan zone, did not settle for a convergence that did not feel right for all in the team, and therefore was able to do a brutal pivot into something everyone felt committed to. This decision generated a very time-constrained situation as they needed to meet the deadline, which helped them to find ways to take turns in the development and use the time zone difference as an asset. The team delivered a triple-wow result. And the supporting cohort, consisting of academic and industry partners, was able to observe how this team managed themselves and their work in a way that provided data for the multi-year study. In February 2020, when Covid-19 caused a dramatic disruption to the intended course plan with canceled trips and students being sent away from their campuses, it was observed that the team was first disheartened by all the bad news. However, then they demonstrated a very impressive team collaboration, leading to a near-perfect EXPE experience in terms of presentation, online marketing material, and a fully functioning prototype. They did it all online, geographically dispersed, during a pandemic. During the multi-year study, a typical team journey emerged, and insights from previous years showed that the combination of wide exploration problem and solution spaces and late convergence led to better project outcomes. This team demonstrated this, despite a very different and challenging year. This study provides an in-depth understanding of innovation engineering skills as we were able to observe the entire team working together on one campus first and then could follow their journey while dealing with unusually challenging hardships due to the Covid-19 pandemic and still achieve a triple wow outcome. This paper has a particularly important role in my research as we, in the writing of it, were able to study team performance in the same way as previous years, and additionally were able to understand the individual team members' experiences since they were globally dispersed.

4.5.2. Relation to thesis

This paper is selected to be part of this thesis because of the detailed understanding of the team dynamics and the individual experiences that we captured thanks to the lockdown during the Covid-19 pandemic. Initially, this study was part of a larger, longitudinal study but became a separate paper with a more detailed understanding.

4.5.3. Author's contribution

Because of an ongoing multi-year study where the research team was already collecting data, shared journaling notes among themselves, and started to see matching patterns across the different student teams, this single case study was possible to conduct. Once Covid-19 hit, Christian Johansson Askling and I realized that this would be a very different year, and I designed the study to involve more students and to go deeper into understanding the team dynamics and team performance throughout the journey, based on the perspective of the students and the teaching team. The concept of a supporting cohort, further used in the following studies, was defined based on the close collaboration between the corporate and academic partners. I led the study in close collaboration with academic partner Christian Johansson Askling and corporate partner Martin Frank. The rest of the research team provided insights, perspectives, and critical questions based on their long-time involvement in the course. Besides designing the study, I also led the collection and analysis of data and identified the pattern that generated a typical team journey map. The typical team journey map represents the pattern that emerged from the multi-year study but has yet to be tested after this paper was presented.

4.6. Paper F. Guiding global innovation teams on their exploration journey - Learning from aspiring engineers

This paper investigates how a supporting cohort can guide an innovation team on its ambiguous exploration journey without interfering with the team's shared knowledge-building and learning and without affecting the team dynamics. We suggest lightweight visual tools for the supporting cohort, where they can observe whether the team is following a typical experience pattern and is maximizing their chances of reaching their fullest potential by having a sufficiently broad problem and solution exploration spaces. This paper responds to the second and third research questions regarding decoding, guiding, and leading exploration, and bridging between exploration and exploitation. The paper was co-authored with Andreas Larsson, Christian Johansson Askling, Tobias Larsson, and Larry Leifer and is submitted to a journal.

4.6.1. Summary

A supporting cohort in an educational setting can guide and coach the student team to maximize its learning experience and, in this course, increase the likelihood of a triple wow. A supporting cohort in a large manufacturing incumbent can, in similar ways, guide and coach the team if provided with the correct tools and can also bridge the explore and exploit sides of the organization because much of the gap between explore and exploit is a lack of understanding. Innovation teams in large organizations can experience a lack of interest and trust from decision-makers, especially in large incumbents where the organizational structure often is hierarchical, and the culture is inclined towards command-and-control leadership. In such an organization, opportunities might be missed, and conceptual solutions might be poorly explored, as the dominant linear development process impact mindsets and decision-making. A conceptual solution might adequately meet one targeted user's needs but might not be competitive or scalable. An innovation team in a large mature organization can be both successful and integrated with the larger organization with a supportive cohort that understands exploration work and provides both air cover and guidance. The awareness that explorative innovation work generates insights about the context and user needs that can generate several solutions concerning several time horizons can bring stability and strategic alignment to an ambidextrous organization (O'Reilly & Tushman, 2016). Innovation teams can be coached on their exploration journeys, like how athletic sports teams are being coached. The supporting cohort must agree not only on which sport to play and what the corresponding rules are in that sport but also on how the team should play the game based on the challenge at hand and the team composition. Just like a sports coach, a person in a supporting cohort is there to help the team work together towards achieving their full potential, which rarely happens by "showing how it should be done." For certain situations on the journey, the supporting cohort can provide tools and tactics - or simply help by asking open-ended questions and giving the team space to reflect. It might be necessary to step in during a rough situation and assist in conflict resolutions or help develop the needed skills to complete a task.

A supporting cohort consists of individuals with different skills and motivations to help the team be their best and reach their full potential. A team journey map can help a supporting cohort to be more effective in guiding an innovation team. A hunter-gatherer map can help the supporting cohort understand whether the team is preserving ambiguity and whether they have expanded the problem and solution spaces sufficiently. Using the two supporting cohort tools can increase the likelihood of a triple wow, breakthrough performance along three complementary systems solution dimensions: design, engineering, and business model, in the educational context. In a corporate context, it can boost the innovation team's performance and increase the understanding and acceptance in the surrounding organization. By capturing both the team dynamics and the team's exploration performance, the supporting cohort might be able to increase the likelihood of success. By adding those two tools, exploration work in education and practice might be better understood and supported, an interesting and relevant future research study.

By utilizing more sophisticated digital tools for global innovation team collaboration and rapid prototyping, it might be possible to synergistically capture both team journey and hunter-gatherer data. This could aid a supporting cohort to quickly notice unwanted situations and take action. From this study, we conclude that innovation engineering work can be systematic and concerted, very different from traditional and linear product development processes, but still possible to coach, guide, and quality assure. In this multi-year study, we identified patterns, connected team performance with individual experience, and observed that late full team convergence leads to better EXPE delivery. Based on findings in this study, we were able to suggest two visual tools for a supporting cohort, one to follow the team on the journey and be ready to guide and nudge as needed, and one to see if the team is expanding their problem and solution spaces sufficiently to reach the furthest on their journey.

4.6.2. Relation to thesis

This paper was selected to be part of this thesis because of the longitudinal nature of the study, where most of the decoding of exploration work was done, where the typical team journey was first notices, and the possibilities to guide a team without interfering with the learning loop three were explored. This study led to my deepened understanding of innovation engineering as both process and practice, which is central to my entire research.

4.6.3. Author's contribution

This is a multi-year study where I have been collecting data for the purpose of understanding the experience and performance of student teams performing innovation engineering. The study was designed to collect data from students every year and look for patterns related to the learning experience and performance. Based on findings in the study presented in paper E, the idea of the supporting cohort and tools for it was developed. When working with a larger amount of data from multiple years, I identified patterns that I could use to design the study leading up to the two tools for the supporting cohort. The team journey map as a tool for the supporting cohort was first suggested in paper E, and the Hunter-gatherer map was first tested as a tool by Christian Johansson Askling for the team studied in the research presented in paper E. The entire research team provided perspectives from their long-term experience of the graduate course and similar courses where design thinking has been applied.

4.7. Paper G. Lost in translation between explore and exploit: From selling products to solving problems in large manufacturing incumbents

This paper examines the difficulties large manufacturing incumbents are experiencing when they try to both explore new innovative solutions and exploit their existing business, with a particular focus on large manufacturing incumbents shifting business orientation from products to PSS. The paper covers a longitudinal study within one large manufacturing incumbent, where innovative PSS solutions have been conceptually proven with customers but not made it to a revenue-generating stage, a study covering several other large incumbents with similar challenges, and insights from a successful shift by HP in the ’90s. This paper research responds to the second, third and fourth research questions. The paper, co-authored with Andreas Larsson, Christian Johansson Askling, Tobias Larsson, and Sheryl Root, has been submitted to a journal.

4.7.1. Summary

During this study, several of the interview respondents referred to the term "innovation theater," coined by Steve Blank (2019), when describing challenges as leaders of exploration-oriented efforts in large manufacturing incumbents. To avoid this, leaders need to communicate and prioritize in ways that make it clear for employees to understand the equal importance and the diametrical difference between exploration and exploitation. A corporate-wide strategic alignment and a future vision that makes a transition from products to PSS solutions logical and attractive. In the study presented in this paper a main focus was on better bridging between explore and exploit to allow promising PSS solutions to progress faster from proven concepts to a revenue-generation stage. The concept of Intentional PSS design is suggested as a way for the explore team to be grounded in what the current business looks like, aim for a wanted future, and identify ways to take the current towards the future in a systematic manner, shaping the future of the company.

It is found in the study that the team performing exploration needs to master innovation engineering skills and understand how to work effectively in a non-hierarchical "community of stars." It is also found that the surrounding organization needs to understand the role and responsibility of the team and the characteristics of exploration work. The buffer role is considered crucial because the buffer leads the innovation team, ensures the team applies innovation engineering skills, provides air cover to expand problem and solution spaces, and connects explore team members with exploit team members when appropriate. The buffer's responsibility is also to be a "corporate whisperer," fully understanding the other sides of the organization and connecting, enabling collaboration and avoiding friction. The companies in this study were large manufacturing incumbents with linear product development processes and traditional decision-making structures. The intentional PSS design approach can provide transparency and rationale to the broader organization regarding why and how specific PSS solutions are selected and how they can generate value for customers and revenue for the company.

The shift from a product manufacturer to an entrepreneurial enterprise needs to be planned and concerted. Strategic alignment and ambidexterity infused in the broader organization, i.e., both the exploitation and exploration mindsets and ways of working, need to be understood and embraced by the larger organization.

4.7.2. Relation to thesis

This paper was selected to be part of this thesis because of the understanding regarding the gap between exploration and exploitation it contributes. It is also particularly pointing out roadblocks and enablers for promising PSS solutions to make it toward revenue generation.

4.7.3. Author's contribution

I led this study which originally only included the multiple cases of PSS solutions not making it to the revenue-generating stage. The data from these cases were collected over multiple years, mainly through my journaling notes, but complemented with data from semi-structured interviews with employees involved in the different cases. Additionally, leaders at other large manufacturing incumbents were interviewed. Co-author Sheryl Root suggested that I interview a former colleague of hers, who had held the role of the leader of HP Labs. During this interview, I learned that it was Sheryl Root who had been instrumental to the successful shift of HP's business model and identity from product selling to problem-solving. This insight led to the Wonder Bread model being described as part of this paper. The other co-authors provided academic expertise and theoretical perspectives.

5. Introducing innovation engineering in practice: Bridging exploration and exploitation in large manufacturing incumbents

In this chapter, a summary of the main research findings is presented, covering three main areas of interest: innovation capability in large manufacturing incumbents, exploration-oriented work in teams, and bridging exploration and exploitation in large manufacturing incumbents. The first area of interest, regarding building innovation capability in large manufacturing incumbents, is primarily presented in Papers A and B, as well as in my licentiate thesis. These papers highlight the challenges faced by throughput-oriented and globally dispersed large manufacturing incumbents in strengthening and maintaining satisfactory innovation capability. The second area of interest, exploration-oriented work in teams, is covered in Papers E and F, as well as partially in Papers C and D. These papers discuss ways to lead and guide innovation teams when they are pursuing exploration-oriented work, and how to maximize their potential. The third area of interest, regarding bridging between exploration and exploitation is primarily presented in Paper C, D, and G. These papers explore reasons behind the gap, how to bridge this gap, and through that, enable a company-wide shift from being product-centric to becoming PSS solution-oriented, and potentially an entrepreneurial enterprise. Throughout my research, I have gained a deeper understanding of the necessity, challenges, and possibilities for futureproofing large manufacturing incumbents. My goal has been to find ways for these firms to holistically shift and renew their organizations while maintaining their current revenue streams. Based on my findings, I suggest integrating exploration with exploitation and recognizing innovation engineering skills as core competencies, alongside traditional deep-discipline engineering skills. Overall, my research contributes to the understanding of how large manufacturing incumbents can revitalize their organizations and remain competitive in an ever-changing market.

Innovation engineering refers to explorative work done in collaborative knowledge-creation processes that can potentially result in new solutions, insights into problems, or innovative methods and practices. The term is used by scholars to describe higher education courses, such as Innovation Engineering: Principles and Methodology at the University of California, Berkeley (Sidhu, 2019). According to Sidhu (2019), innovation engineering is the outcome of utilizing entrepreneurial and innovative approaches, processes, behaviors, and mindsets in engineering projects. Lund University's Faculty of Engineering in Sweden has an Innovation Engineering division that offers an undergraduate course, INTN01 (LTH, 2022), which covers the interdisciplinary subject from technical, human, and business perspectives. The Product Innovation Engineering program, PIEp, was a Swedish national research and education program between 2006 and 2014 that aimed to shift engineering education towards innovation and entrepreneurship (Grimheden et al., 2007). The PIEp program involved multiple academic institutions, industrial partners, and an extensive international network. In this program, innovation engineering was described as both an ability to create conditions for innovation and as an innovative power in developing engineering products, involving the development of innovative organizations, processes, and people with the capacity to create value through new products and services.

In this research, the term "innovation engineering" has been a useful concept for distinguishing between exploratory and exploitative work. As suggested by Sidhu (2019), innovation engineering involves an ambiguous, divergent, and convergent exploration journey where a high level of diversity and multidisciplinarity increases the likelihood of involving the necessary skills and perspectives. My own understanding of innovation engineering has been developed through my studies of both student teams (Papers E and F) and industrial practices (Papers C, D, and G). The results suggest that innovation engineering is a team-based exploratory process that involves various approaches, tools, mindsets, and skills to address open-ended, ambiguous, or complex problems, generate new knowledge, and potentially radical innovations. When a team practices innovation engineering, the team members embark on a joint exploration journey aimed at achieving a shared understanding of an agreed-upon problem and developing new knowledge that can potentially lead to one or several satisficing solutions (Simon, 1956). The process might be described as an exploratory journey unique to each team, starting with a context and an initial open-ended problem statement and ending with a satisficing solution that a targeted user can validate.

The number of iterations and pivots the team needs on their journey, as well as tested and failed prototypes, are not predetermined but part of the team's unique path.

The context for this research is large manufacturing incumbents, and an early observation was that one might be able to strengthen a company's innovation capability by increasing the number of employees who understand innovation engineering (see Papers A, B, and G). Additionally, a systematic and transparent approach to innovation engineering enables the larger organization to be better prepared to adopt new ways of solving customer problems and adapting to new business models (see Papers B, C, D, and G). Effective leaders at different levels of the organization demonstrate "both-and" leadership, leading in a way that makes organizational ambidexterity observable and present through both communication and action. By enabling company-wide organizational renewal and gradual realignment towards a new regime without neglecting current competitive advantages, these leaders provide financial stability near-term and long-term (see Papers A, B, and G). In following subchapters, I summarize the research results based on the findings presented in the appended papers under the categories:

- Building innovation capability
- Innovation engineering in practice
- Bridging between exploration and exploitation

5.1. Building innovation capability

Building innovation capability in large, globally dispersed matrix organizations is essential for their long-term survival and success, yet it is a complex challenge. Factors such as organizational inertia, cultural differences, local site conditions, varying roles and priorities, multiple competence domains, and leadership considerations can significantly impact the process. In large manufacturing incumbents, the focus on reliability, accountability, and reproducibility intentionally leads to high organizational inertia (Hannan & Freeman, 1984) but may pose a significant threat to a company's longevity in a dynamic environment that demands rapid adaptability and organizational flexibility. The studies presented in Papers A and B confirm that establishing and strengthening innovation capability in a large and globally dispersed matrix organization is challenging and will take time. To institutionalize innovation engineering skills, starting with a low-risk initiative with a small team focused on exploration can be effective if, at the same time, executive leadership demonstrates clear strategic intent and an ambidextrous, or "both-and", leadership in both communication and action, and make sure the ambidexterity is infused throughout the hierarchical layers and across functions.

My findings regarding building innovation capability in large manufacturing incumbents can be summarized in four key components, 1) Establish an innovation capability framework, 2) Measure the progress, 3) Promote and educate a network of ambassadors, 4) Infuse organizational ambidexterity into the entire organization.

5.1.1. Establish an innovation capability framework

In my role as a global director within the R&D function at Volvo CE, I led an initiative to strengthen the company's innovation capability (also described in my licentiate thesis). Before the studies presented in Papers A and B, my team and I developed a company-specific innovation model, i.e., an innovation capability framework. The Volvo CE innovation model was developed through a combination of literature studies, discussions within the core team, benchmarking with other companies, and collaboration with academia and has been central in the continued work and my research. Although this framework is not a pure research outcome, it is included in this thesis because it has been integral to both the company's development and the research.

An agreed-upon, executive management-approved innovation capability framework allowed us to develop the other three key components. The presented innovation capability framework is not intended to be universally valid for all organizations but can serve as inspiration. The following section presents how the nine factors in the innovation capability framework were applied. Worth mentioning is that I have, in my research, changed the wording of the nine factors, so it is slightly different from the wording within the company.

The nine factors explained and strengthening activities exemplified from the Volvo CE case:

User and customer centricity

User- or customer-oriented mindsets and methods are in focus, rather than product- or business model-oriented, because a need-based approach to innovation stays relevant longer. Examples of strengthening activities are enabling and encouraging customer interactions, training sessions, and guiding literature to increase employees' familiarity with the design thinking approach and need-finding methodology. Student projects where customer problems were in focus and where the students explored both problems and solutions “zoomed out” from our physical artefacts served as knowledge-building and inspiration within the company as well as for partners, suppliers, and customers.

Fostering an innovative culture

An innovative culture is fostered by the behaviors, attitudes, shared beliefs, incentives, and values that reinforce innovation work. When a culture focused on efficiency and quality is already established, efforts must be made to incorporate curiosity, creativity, and collaborative practices. One effective approach we used was to lead by example with our small team, despite facing ridicule – and to encourage these practices at all our locations worldwide. It is not difficult to find employees who are eager for this type of environment. We recognized that we might not initially be welcome, but we persisted in bringing up the topic of innovation during meetings where quality, efficiency, and quarterly results were discussed.

Sharing ideas to create value

Sharing ideas rather than working alone is more likely to generate customer-value innovations. Encouraging the use of collective intelligence is crucial for fostering innovation. This involves promoting the sharing and development of insights, problems, and ideas among employees. To achieve this, we organized global innovation days, where everyone was invited to contribute as part of a team. We also created an online platform that combined idea-sharing with our front-end innovation process. Furthermore, we experimented with innovation groups, or "iGroups," which were comprised of multi-disciplinary teams given the freedom, budget, managerial support, and guidance from an external coach to innovate.

Shaping the future

To provide employees with a direction to strive for, it is necessary to establish future goals and anticipated scenarios based on foresight and imagination. At Volvo CE, we developed a long-term roadmap to inspire and challenge our colleagues by addressing the future of the industry and enabling technological advancements. The initial version of the roadmap was created in 2009 and has been continuously presented and discussed internally. One version of the roadmap was communicated in a video online that can be found on YouTube (VCM Belgium, 2013). In this video clip the future of the construction industry is visualized and explained. It shows how things might look like and work in a future without emissions, accidents, and unplanned stops, and with a dramatically improved productivity.

We also collaborated with academia and student teams to pursue exploration-oriented projects, which were presented to the entire organization and occasionally to external audiences to promote our aspirational future scenario.

Clear innovation process

A clear innovation process encourages all employees to contribute and participate while following and building on each other's insights and ideas. An online platform has been implemented to make the process accessible and understandable, featuring a non-directional idea-sharing area and a linear process for globally prioritized investigation projects. The linear process is user-centric, featuring steps such as seed (an idea suggested for investigation), sprout (a selected idea under investigation), and flower (a finalized investigation with documented knowledge building and often a follow-on project proposal). The patent process has also been incorporated into the open sharing space, with patent managers monitoring potentially patentable ideas at an early stage.

Both-and leadership

A "both-and" leadership in terms of action and communication is necessary. This refers to executive leaders who demonstrate and promote organizational ambidexterity. In the case of Volvo CE this was represented by "clear owner" because of the strict hierarchical structure. As the organizational structure varies in different organizations, I have adjusted my example of an innovation capability framework to "both-and leadership". This requires a clear and well-known strategic intent, a leadership style that balances exploration and exploitation, both in action and communication. In some organizations, executive leaders might need to promote and protect exploration efforts. At Volvo CE, the support from a few executive leaders (vice presidents and senior vice presidents) was sufficient to keep the initiative alive through the economic cycle. The executives provided protection, support, and encouragement, provided connections, and removed roadblocks.

Committed management

This refers to the previously mentioned "both-and" leadership but now addresses leaders at all levels and in all functions of the organization. This means that leaders need to not only tolerate but also actively contribute with a balanced approach that values both exploration and exploitation. One example of how we promoted this approach at Volvo CE was that we provided basic education to managers. However, we were unable to make the training mandatory due to leadership considerations, so it was mostly the already committed ones that participated.

Inspired at work

An inspiring working environment involves both the physical office experience and the online, digital experience. It refers to how the environment one works in needs to remind about, promote, and enable ideation, exploration, and co-creation. At Volvo CE, we also learned that the corporate office conditions weren't enough to spur inspiration – access to real-world users, customers, and partners (i.e., dealerships, suppliers, academia) was also necessary. This was addressed by encouraging and enabling customer job site visits and arranging dialogue meetings with customers and users. It was also addressed by establishing innovation rooms on the local sites. The digital working environment was improved, partly through more intranet communication about customers and innovation. We also implemented a dedicated online platform for idea sharing and the front-end innovation process. This platform was developed in collaboration with the external partner Kodamera in Sweden, and the platform was named Interact. Before deciding to develop our own solution, we investigated off-the-shelf alternatives, but none of them offered the transparency and inclusiveness we wanted to have, and none of them were cost-competitive either.

Time for ideas

This is a difficult factor in large manufacturing incumbents' organizations as resource efficiency is in focus but still a necessity. It is about creating enough slack for individuals and groups of people to explore, i.e., having a free-flowing, collaborative, knowledge-building, creative process. At Volvo CE, we observed that the "efficient" approach to only using occasional "gap" time between urgent deliveries is not enough. Relying on employees' individual spare time is not sufficient either. Examples of how this factor was addressed include studies of how the efficiency focus kills creativity and how employees experience being involved in too many different projects. These studies were performed together with academic partners, and both Ph.D. and graduate students' thesis projects have been instrumental.

The innovation capability framework employed in this study proved essential for both research and practice. At Volvo CE, it enabled productive discussion, interpretation, and contextualization with local management and colleagues, facilitating diverse understandings and approaches across sites and ultimately contributing to strengthened innovation capability globally. The innovation capability framework consists of nine equally important factors, with the freedom to select focus depending on the current status. For example, in our study, we consistently prioritized the factor user and customer centricity as a way to facilitate a shift from the company's strong emphasis on physical products. Figure 15 presents one possible depiction of the framework.

Figure 15. An innovation capability framework, consisting of 9 essential factors, can be depicted in various ways, fun and boring ones. Here is one example.

5.1.2. Measure the progress

A contextually relevant and actionable innovation measurement system that provides holistic information about the status of the company's innovation capability enables focus on the work and more impactful prioritized actions. The measurement data aids the work in promoting wanted behaviors, diagnosing status to identify needed actions, experimenting with corrective actions, and serving as a tool for nudging, reflective thinking, and sharing. In this research (see paper B), we selected the MINT framework (Nilsson et al., 2010) and implemented it in a way that involved employees across the organization; therefore, the system included relevant and actionable metrics. We also included the already existing innovation capability framework, mentioned earlier in this chapter. Our approach made it possible to embrace the complexity and the multiple layers in the globally dispersed matrix organization and still assess progress and agree on actions between the data collection points. With metrics that were both relevant and actionable, it was possible to use the innovation measurement system in the following four ways:

- To promote behavior, processes, future goals, and tools (nudging),
- To diagnose the organization, per local site, per function, and globally, and take corrective actions,
- To experiment with what metrics to collect and how to collect them,
- To reflect on results and develop a shared understanding and calibrate ambitions.

An insight from implementing the innovation measurement system is to get started with *something* rather than strive for a perfect solution because a delayed launch means missing out on learning opportunities. With the combination of manually collected data, a company-wide survey, and some automated data collection, the measurement system became robust and useful in the four ways mentioned before.

Examples of corrective actions that were taken based on innovation measurement results are:

- Adding workshops, training sessions, and internal communication, based on results showing that employees were not familiar with processes and tools,
- Having candid conversations with leadership to increase their knowledge about the need for ambidexterity and to learn about their challenges,
- Strengthening site-specific work with the help of the local leadership and the innovation ambassadors.

The innovation measurement results also provided data regarding the R&D portfolio balance, the number of filed patents, customers' perception of the company versus its competitors, and the number of new innovative content in market-launched solutions. The data consistently showed a gap between successful exploration outcomes (initially proven concepts) and new innovative content in market-launched solutions. Physical product sales volumes and margin per sold product were the predominant views of the company's business. At that time, the general interpretation of being a "total solution provider" was to sell products with optional service contracts as addons. The disconnect between customer-centric exploration outcome and product-centric exploitation was obvious and intentional, as the company had defined both the organizational structure and the core processes with the same disconnect, see Figure 16.

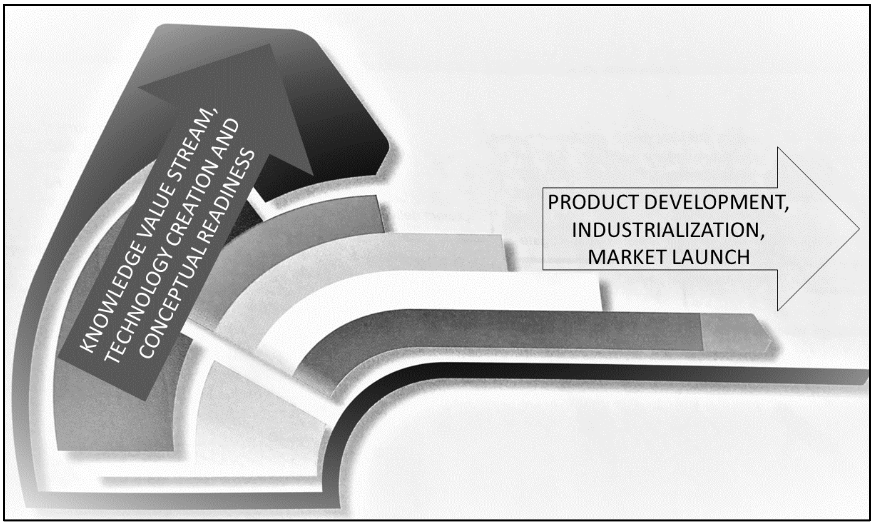


Figure 16. Schematic picture of the project model applied at Volvo CE, adapted from Volvo CE (2017).

The measurement system facilitated the consolidation of global, site-specific, and functional organization-specific data, enabling both tactical (site-specific as well as function-specific) and strategic (global) improvement efforts. Progress was achieved through "top-down" global, local, collaborative, as well as competitive across sites and functions interactions. This initiative contributed to the enablement of new innovative solutions, such as battery electric compact equipment, autonomous and connected transport solutions, and active safety features. The approach also inspired engineers to engage in exploration-oriented work and promoted an innovative culture on all sites.

5.1.3. A network of innovation ambassadors

To build innovation capability in a globally dispersed organization, a combination of global and local strengthening efforts is necessary (see also subchapter 5.1.2). A successful approach (see paper B and my licentiate thesis) is to establish a global network of innovation ambassadors, or coaches, to lead the initiative through engagement and education. An innovation coach serves as an ambassador for the innovation capability-building initiative within the organization, providing support and guidance to colleagues and offering insight into local cultures and conditions to inform the initiative's processes, methods, approaches, and communication. A global network of innovation coaches can function as a backbone of a large, globally dispersed organization's innovation capability building, driving a top-down message and common processes while representing and operating on local sites. Combining a global and local lens is beneficial in innovation capability building to avoid misunderstandings and leverage site-specific strengths. Establishing a global innovation coach network as an extended team to a core exploration team spreads innovation engineering skills and integrates exploration with exploitation despite high organizational inertia.

My experience is that this role needs to be a part-time role in order to secure close and strong connections to local colleagues. At Volvo CE, the iCoaches were given the following responsibilities:

- Educate, coach, and support leaders and colleagues in building innovation capability,
- Contribute to the measurement initiative (see chapter 5.1.2) by data collection, analyzing and sharing of results, and identifying prioritized corrective actions,
- Moderate conversations in the online idea sharing platform, with a focus on sharing insights and ideas,
- Function as a bridge between global and local initiatives. Share knowledge, best practices, and learnings from failures across the organization, locally and globally,
- Lead and facilitate creative meetings and workshops.

An organization's innovation coach network comprises locally rooted and globally connected innovation leaders and change agents, offering robust support for company-wide capability-building initiatives. The network serves as both an encouraging support group for tackling challenges and a scaling mechanism for implementing effective solutions (proven on one site) across sites. Management commitment close to the innovation coaches is important, especially during cost-saving times, where the innovation coach network needs to be prioritized and emphasized to prevent organizational inertia from pulling back to non-negotiable near-term financial results. Expectations on the innovation coaches, from both local and global leadership, further reinforce the importance of innovation capability building.

5.1.4. Infuse organizational ambidexterity into the entire organization.

Findings in this research (see papers C, D, G) suggest integrating exploration work into the larger organization to build company-wide innovation capability is beneficial. It has been identified that a limited understanding of exploration skills and practice limits the involvement of strategically important competencies outside the exploration-oriented core team. Proactively designing, documenting, and sharing exploration processes, tools, and methods can increase both understanding and potential of involving colleagues from the broader organization. Furthermore, findings in the research presented in papers E and F emphasize that exploration can uncover multiple problems to solve, and multiple corresponding solutions, some of which may be feasible in the near term while others may require technological advancements or business model innovation. To establish a systematic way to thoroughly document and share exploration journeys might be a competitive advantage and ensure futureproofing for companies that are committed to the long game (Sinek, 2019).

Integrating temporary team members from the exploitation-oriented side into exploration-oriented teams presents challenges, as reported in papers D and G. Priming such members, particularly colleagues that are used to be the "go-to" expert, for exploration-oriented mindsets and approaches, is necessary. The priming needs to include both the individual shift towards a beginner's mindset and the procedural shift from the linear stage-gate process to the iterative and non-linear exploration journey where collective knowledge and perspectives are utilized when exploring possibilities. It is observed that internally appointed specialists in large manufacturing incumbents commonly overestimate their knowledge in emerging technology domains, lack innovation engineering skills, exhibit defensive behavior, and push for formalized collaborations with predetermined requirements and clear interfaces instead of joint exploration. Without the previously mentioned priming, bringing in an internal expert may damage relationships with external exploration partners and cause delays.

As presented in paper D, these issues might be mitigated with problem-solving mechanisms that can be utilized in all sorts of collaborations, internally across the organization or externally with suppliers, customers, dealers, and startups. The following problem-solving mechanisms are suggested:

1. To ensure the relevance of an idea, it's important to vet the context, technologies, and customer needs with internal colleagues. This helps mitigate internal antagonism and "not-invented-here" problems. Organizations that value exploration as much as exploitation facilitate and encourage this kind of vetting.

2. Create mutual ownership by involving all relevant colleagues early on and ensuring that everyone has a vested interest in the project's success. For example, a technology specialist can help define the project scope or responsibility split. This approach benefits both the project and the broader organization, as knowledge-building extends beyond the exploration core.
3. Establish a mutual understanding of confidentiality by ensuring that all parties have the same understanding of what is confidential and needs to be managed through non-disclosure agreements and other contracts. This is crucial for effective exploration work in partnerships, especially with small technology startups. Safeguarding involves managing existing intellectual property before starting the co-creation process, securing individually owned IP upfront, and explicitly defining each partner's property. By doing so, the collaboration contract can be straightforward and enable agile collaboration.

In summary, the fourth component of innovation capability in large manufacturing incumbents, i.e., infusing organizational ambidexterity into the entire organization can be described as follows:

- Become a **proficient exploration collaborator**. This entails grasping both the internal conditions and external partners' needs, drivers, and concerns, preferably before starting the collaboration,
- Consider **innovation engineering** skills and practice strategically important core competencies (equal to other core competencies, but much different) and ensure that all employees have insight into the exploration-oriented work and that all employees are offered basic training.

The research identifies a lack of understanding of innovation engineering skills and practices among several large manufacturing incumbents, which threatens their ability to future-proof themselves. Additionally, many of these companies do not appreciate the strategic importance of exploration-oriented work, i.e., innovation engineering skills and practice. The following subchapter presents the author's findings related to this challenge, providing insights for companies seeking to address this issue.

5.2. Innovation engineering in practice

Through literature reviews, the case studies presented in Papers E and F, my involvement in a study of multidisciplinary innovation teams I called iGroups (Johnsson, 2016), and my own experience from building and leading teams at Volvo Group, I have gained a comprehensive understanding of innovation engineering in practice. The highest-performing innovation engineering teams are multidisciplinary, value team diversity, maintain high levels of psychological safety, and view failure as a learning opportunity without judgment. Teams with high levels of autonomy are best suited to using truly explorative and agile methods, leading to a greater likelihood of achieving breakthrough or radical innovation.

The next three subchapters summarize the findings on innovation engineering in practice. The first subchapter focuses on the team's internal dynamics, the second subchapter discusses ways for a supporting cohort to guide the team, and the third subchapter addresses the essential "buffer role" in large manufacturing incumbents.

5.2.1. The inner life of the team

My understanding of the "inner life" of an innovation engineering team is developed through the studies presented in papers E and F. One finding is that a team shows great potential, as well as resilience and adaptability through the journey, if it is early in their collaboration, has established strong social connectedness, and share workload and responsibilities across the team dynamically. When a team consists of individuals that are united by a shared motivation to accomplish something extraordinary, it can further increase its likelihood of success by building social connectedness. Additionally, it can strive for the following team characteristics:

- The team has no assigned roles; instead, it functions as a "community of stars" where all of them contribute with their unique skills and perspectives, value their peers as equals and enjoy spending time together,
- The team operates under a shared responsibility paradigm, where they take turns in leading and following, supports each other, and prevent peers' disengagement and suboptimal performance,
- Even during difficult times, such as in the "groan zone", where the sum of all individual and shared knowledge need to lead to a decision, the team maintains positive communication and high regard for each other,

- The team actively and consistently utilizes its diversity and other differences as assets. This includes individual skills and perspectives, work habits, and time-zone differences.

The team's inner life is where learning loop three (Leifer & Steinert, 2011) takes place, where social connectedness, shared mindset, and commitment to each other make the team strive for extraordinary achievements. While this learning loop belongs to the team, a supporting cohort can provide an environment and leeway for the team to "keep calm and carry on" throughout their ambiguous journey.

Findings in papers E and F regarding what a supporting cohort can observe and guide regarding the inner life of an innovation engineering team can be summarized as follows.

Social connectedness in the global team is essential

Teams that establish social connectedness from the start of their collaboration approach the joint learning experience as equals, leverage differences as strengths, and navigate the groan zone with patience and grace. Teams that have established social connectedness outperform other teams as those teams utilize the whole team's diverse skills, cognitive preferences, and perspectives to develop a shared understanding of the problem and are able to jointly select the satisficing solution (Simon, 1956) they want to build and validate. While a supporting cohort can encourage social connectedness through social activities, it is crucial for the team to create and nurture social connectedness on their own.

Preserving ambiguity is hard, but takes the team further

When some team members latch onto a favored solution (far too early), it is challenging, sometimes impossible, for their peers to steer the entire team towards reconsideration, often leading to the formation of sub-teams. The best approach for a supporting cohort to avoid this situation is to remind the team to preserve ambiguity, as delaying final convergence leads to better results. A supporting cohort may need to intervene when the team's **need-finding is too narrow**. For example, if the team fixates on one user's need and fails to explore further, resulting in a logical but unremarkable solution. Additionally, if the team conducts **too limited benchmarking**, they may miss existing solutions or fail to address industry-wide ambiguous problems, warranting intervention from the supporting cohort. In the following subchapter, two tools for the supporting cohort are suggested.

5.2.2. Tools for a supporting cohort

Our research highlights that successful supporting cohorts must agree not only on the game the team is playing and its corresponding rules but also on how the particular team composition needs to play the game and what challenges this particular team is anticipated to face. Similar to a sports coach, a member of the supporting cohort aids the team in reaching its maximum potential. However, this support must be provided without disrupting team dynamics or interfering with the team's work. It is crucial that all in the supporting coach avoid showing the team "how to do it" and instead encourage them to find their unique path. In this research, we suggest two tools for the supporting cohort; the team journey map, see Figure 17, and the hunter-gatherer map, see Figure 18.

By having those tools as calibration visuals, shared among themselves in the supporting cohort, they can nudge and guide a team toward its maximum potential. The tool called "team journey" will help the supporting cohort identify challenges in the team's inner life. The tool can either be applied as an observation tool, not shared with the team, or as an interactive tool where team members are asked to rate their experience. The tool called "hunter-gatherer map" will help the supporting cohort to follow the exploration journey based on the team's prototypes.

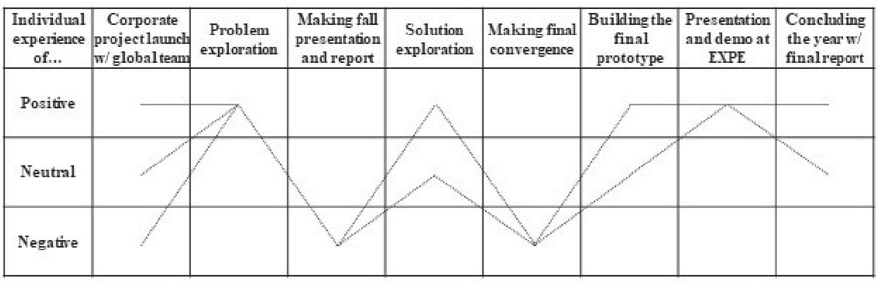


Figure 17. Team journey map from the multi-year case study.

Findings in this research suggest that innovation engineering can be taught, systematic, structured, and concerted. It also suggests that a supporting cohort can guide a team towards breakthrough or radical innovation without interfering with the team's learning loop three.

In a large manufacturing incumbent, it might be possible to engage a supporting cohort, but it is absolutely necessary to have an individual taking on the buffer role, which the following subchapter is focused on.

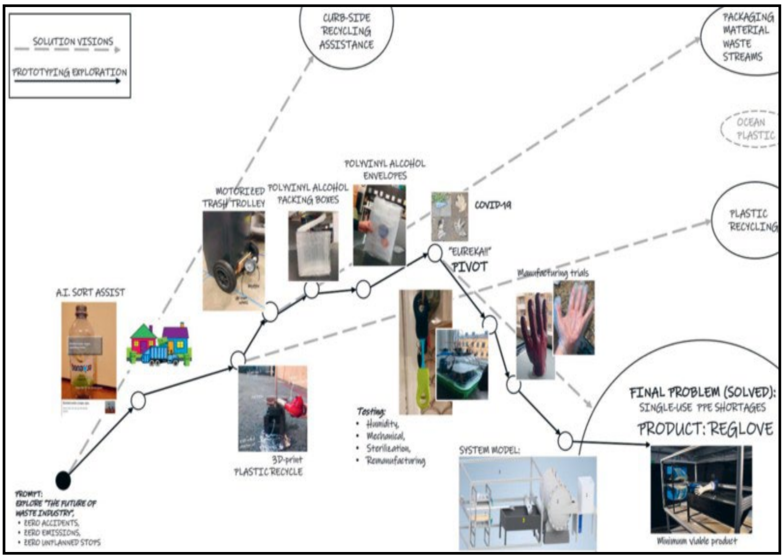


Figure 18. The hunter-gatherer map from the Covid-19 year, by Johansson Askling (2021).

5.2.3. The buffer role

As presented in papers C and G, the establishment of an innovation engineering team requires a leader willing to take on the buffer role. To ensure successful exploration work, innovation engineers should be shielded from the larger organization's traditional linear product development process and organizational inertia, which is particularly important when "both-and" leadership is not yet adopted throughout the organization.

An innovation engineering team requires individuals with exploration skills and mindsets, which are not commonly considered core competencies in large manufacturing incumbents nor traditionally listed in HR systems. Thus, a leader is needed to act as a buffer between the innovation engineering team and the larger organization. This leader should represent the interests of both sides and promote understanding and collaboration between them.

The buffer role needs to be understood and accepted by all individuals involved. For a large manufacturing incumbent that decides to increase its focus on exploration, it might be helpful to proactively reflect on the following questions:

1. What is the intent?
2. What ultimate outcomes will be our measures of success, and what indicators would tell that we are progressing toward that?

3. Do we have employees with the right competencies and mindsets, and do we need new talent?
4. Are we willing to apply a long view that allows for establishing and cultivating a high-performing innovation engineering team, or do we need to find an external partner?
5. How will we integrate exploration with exploitation in the larger organization?
6. In terms of decisions, communication, and follow-up, what actions are needed on the executive leadership level to enable the expected success?

Research indicates that unanswered questions, particularly those related to bridging exploration and exploitation, can cause misunderstanding, and disconnect between exploration-oriented functions and the larger organization, especially when the C-suite connection is weak. Failure to pursue promising, conceptually proven integrated solutions can result in lost business opportunities, lost knowledge, and lost motivation, leading to decreased company longevity. This gap has been observed in previous cases, such as Kodak, Nokia, and Facit. Capturing and sharing tacit knowledge obtained during the exploration journey is difficult, and therefore it is vital to bridge the gap between exploration and exploitation (Bertsch et al., 2015; Häikiö, 2002; Sandström, 2013). Findings regarding how to bridge between exploration and exploitation are summarized in the following chapter.

5.3. Bridging exploration and exploitation

To futureproof large manufacturing incumbents, bridging between exploration and exploitation is essential. Isolating exploration as an activity that is protected from the exploitation-oriented organization is only the first step toward becoming a truly innovative company. It is crucial to bridge between exploration and exploitation to enable organizational renewal and realignment and a shift from transactional products to relational PSS solutions. This shift requires new depths of partnerships in the value constellation, developing new uses of the product and contextual data, and fostering new customer interactions. This ensures that exploration efforts align with the company's "raison d'être" and enable flexibility and responsiveness to environmental changes. By doing so, the organization can avoid falling into the trap of innovation theater and focus on sustainable long-term performance.

In the research presented in papers C and G, it was observed that bridging is often expected to be something that the exploration-oriented side of the business should focus on, while the rest of the company should continue with its business as usual. Therefore, the role of the leader (buffer) of an exploration-oriented team tends to become a bridging role, where the leader needs to understand the drivers and motivations of all the internal functions, translate those to the exploration-oriented team and translate results from the exploration work to the different parts of the organization. In the research presented in paper G, respondents indicated that this individual would be more likely to succeed when directly reporting to a C-level executive. Based on the finding in my research, I suggest that the bridging should be done in three different directions:

Top-down: C-level executives should display "both-and" leadership by explicitly promoting a top-down approach for strategic alignment across functions, layers, and sites, prioritizing organizational ambidexterity. They must comprehend exploration and exploitation to bridge the two sides effectively, avoiding wasted effort and time.

From exploitation towards exploration: Leaders must bridge exploration and exploitation by demonstrating their equal importance through leadership behaviors, such as meeting agendas, performance follow-up, and rewarded actions. Even leaders responsible for only exploitation need to be aware of the need for innovation engineering skills as core competencies. However, a large manufacturing incumbent's organizational inertia may hinder radical innovation and renewal, pulling toward predictable, efficiency-oriented work. Therefore, leaders must receive support to maintain a trustworthy both-and leadership.

From exploration towards exploitation: To bridge from exploration to exploitation, the exploration team must understand the larger organization's predictable, linear processes and how their work relates to other parts of the organization, including existing capabilities, dependencies, and relevant knowledge exchanges. This understanding must align with the organization's reliability, accountability, and reproducibility for revenue generation and stability. The exploration team should transparently document their project progress and involve colleagues accordingly. Ultimately, the individual with the buffer role must take responsibility for this bridging process.

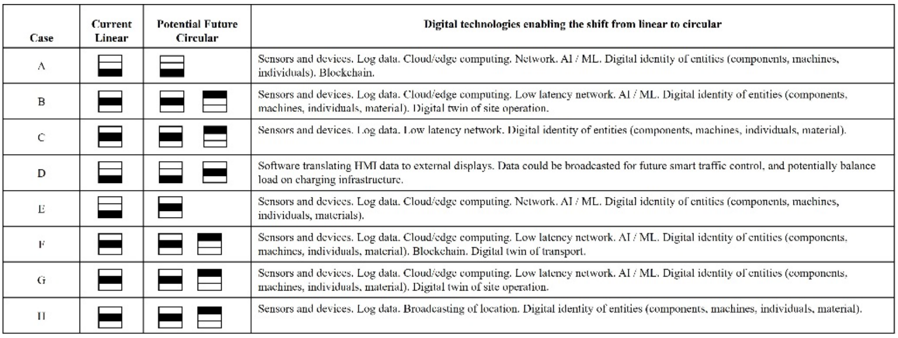
Establishing a bridging between exploration and exploitation from three different directions will balance current and future success. Shifting from a product-centric to a PSS-solution-oriented company requires changes in structures, processes, business models, mindsets, and identity. To bridge the gap between exploration and exploitation is challenging on its own. To also make a company-wide shift from product-centric to PSS oriented is another equally difficult challenge. In this research, the following two “bridging approaches” are suggested:

- Intentional PSS design, which is intended as an innovation engineering tool, but additionally shows promise in functioning as a bridging approach.
- Standardized solution visualization for decision-making, which is inspired by how HP shifted their business focus from selling products to solving problems, which also shows promise in functioning as a bridging approach.

This is further explained in the following two subchapters.

5.3.1. Intentional PSS design

Figure 19 shows a structure for innovation teams to consider both different system levels and different time horizons when exploring problem and solution spaces. The intentional PSS design approach builds on a new discourse for PSS design, suggested by Lugnet et al. (2020) and the three-step framework, now-wow-how (Ericson & Törlind, 2013). The team starts with "what is", analyzing existing offerings, operational processes, and societal systems. Then, the team envisions the "wow", disregarding limitations to imagine almost impossible futures and optimal solutions, and finally focuses on "how" to shift from a product-centric to a PSS-oriented business model, with both physical artifacts and digital components. The intentional PSS design approach enables adaptable value delivery tailored to specific customers' needs, allowing for evolving PSS solutions over time. The organization can build on existing knowledge, and strong customer relations and offer new innovative and evolving PSS solutions by applying this approach.



Case	Current Linear	Potential Future Circular	Digital technologies enabling the shift from linear to circular
A			Sensors and devices. Log data. Cloud/edge computing. Network. AI / ML. Digital identity of entities (components, machines, individuals). Blockchain.
B			Sensors and devices. Log data. Cloud/edge computing. Low latency network. AI / ML. Digital identity of entities (components, machines, individuals, material). Digital twin of site operation.
C			Sensors and devices. Log data. Low latency network. Digital identity of entities (components, machines, individuals, material).
D			Software translating HMI data to external displays. Data could be broadcasted for future smart traffic control, and potentially balance load on charging infrastructure.
E			Sensors and devices. Log data. Cloud/edge computing. Network. AI / ML. Digital identity of entities (components, machines, individuals, materials).
F			Sensors and devices. Log data. Cloud/edge computing. Low latency network. AI / ML. Digital identity of entities (components, machines, individuals, material). Blockchain. Digital twin of transport.
G			Sensors and devices. Log data. Cloud/edge computing. Low latency network. AI / ML. Digital identity of entities (components, machines, individuals, material). Digital twin of site operation.
H			Sensors and devices. Log data. Broadcasting of location. Digital identity of entities (components, machines, individuals, material).

Figure 19. The three-level intentional PSS design approach.

In this research, the intentional PSS design approach is also identified as a promising way of bridging exploration and exploitation, especially in firms transitioning from product-centric towards integrated PSS solutions. The now-wow-wow framework has been instrumental several times during my research journey, and the new discourse for PSS design (Lugnet et al., 2020) provides a systematic approach to the necessary "zooming in / zooming out" capabilities. Intentional PSS design can provide benefits beyond Innovation Engineering practice when shared transparently with the broader organization. Increased understanding and acceptance of novel integrated solutions can lead to faster, more flexible, and delegated decision-making processes, allowing companies to gain a first-mover advantage (Montgomery & Lieberman, 1988) and override any spinal reaction to take control in a traditional, hierarchical command-and-control manner. Additionally, the intentional PSS design approach might help companies avoid confusing market dominance with technological competence by identifying strengths and knowledge gaps.

5.3.2. Standardized solution visualization

Another approach that can help with decision-making regarding promising PSS solution concepts is inspired by HP's Wonder Bread model, explained by Sheryl Root as presented in paper G. The idea with the approach is to visualize new business opportunities in a way comparable with existing customer offerings so that bias towards what exists already can be overridden, or at least consciously managed. The approach helps conquer denial in large manufacturing incumbents where success has been based on prioritization of operational efficiency, cost reduction, and incremental product innovation. This approach involves visualizing and tracking concepts in a two-dimensional chart, with the y-axis representing actual and anticipated market adoption and the x-axis representing the age of the explored concept. Concepts are represented by balloons, with the color indicating market readiness and the size representing the anticipated or actual market. The value can encompass what a customer is willing to pay or other values, such as the customer's reduced cost of operation, or reduced CO2 emissions. Figure 20 demonstrates conceptually how the visualization might look.

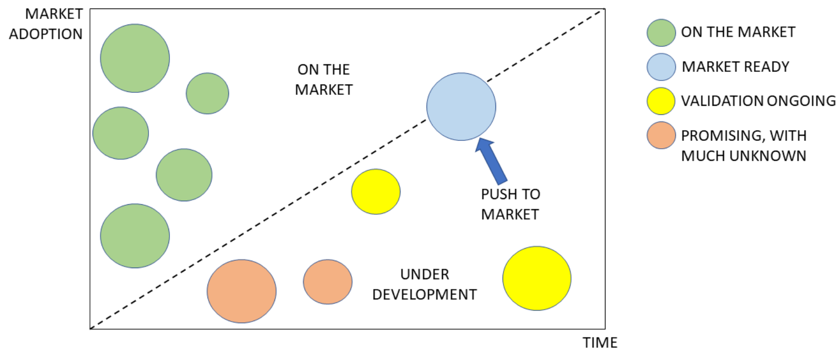


Figure 20. The conceptual Wonder Bread model (as described by Sheryl Root).

To facilitate decision-making for PSS solutions in large manufacturing companies that traditionally rely on physical artifacts and anticipated sales pricing, a standardized visualization tool such as HP's Wonder Bread model can be used to bridge the gap between the old (exploit) and new (explore) business models. This approach can aid in communicating a shift from being product-centric to becoming a PSS-oriented organization. Although this approach has not been evaluated in this research, its potential usability in large manufacturing incumbents looking to transition from products to PSS solutions has been proven within HP and is both simple and promising enough to be explored in future research.

In this chapter, findings from almost seven years of part-time research have been summarized. It covers understanding of and suggestions on how large manufacturing incumbents can strengthen their innovation capability. It covers an understanding of and suggestions on how exploration-oriented work can be conducted and supported, as well as a proposed definition of innovation engineering skills and practice. It also covers understanding of and suggestions on how to bridge between exploration and exploitation in large manufacturing incumbents. The research is based on theory, and the design research methodology is applied in parallel with my industrial practice. My motivation for this research stems from witnessing the work of exceptional innovation engineering teams and their promising solutions being lost in the gap between exploration and exploitation. I sincerely believe that large manufacturing incumbents can futureproof themselves – if they only get out of their own ways.

6. Conclusions and future research

This chapter draws the final conclusions of the research in relation to the four research questions stated in the introduction chapter.

The first research question (RQ1) regarding how large manufacturing incumbents can strengthen their innovation capability is based on findings in this research answered as follows. Large manufacturing incumbents can strengthen their innovation capability by applying the following four key components or cornerstones:

- An innovation capability framework, in this research the framework has consisted of nine essential factors and has functioned as a valuable and consistent foundation for continuous innovation capability building in a large, globally dispersed manufacturing incumbent's organization,
- It has been found necessary and effective to measure innovation capability in a holistic, contextually relevant, and actionable manner,
- Establishing a global network of ambassadors, or innovation coaches, with both global and local perspectives, has been instrumental in building innovation capability across a globally dispersed organization,
- Infusing organizational ambidexterity into the entire organization is deemed necessary, which entails establishing exploration understanding in an exploitation-oriented organization.

These components have been derived based on empirical research and theoretical foundations. It is suggested that their implementation will enable large manufacturing incumbents to future-proof themselves and maintain their competitive edge in the face of rapid technological and marketplace changes. The construct based on these four components, or cornerstones, has been proven to be flexible and resilient, surviving economic cycles and organizational changes.
The second research question (RQ2) covers how exploration can be institutionalized, guided, and led by large manufacturing incumbents. In this research, I have gained a deepened understanding of innovation engineering as a team-based exploratory process that involves various

approaches, tools, mindsets, and skills to address open-ended, ambiguous, or complex problems, generate new knowledge, and potentially radical innovations. Through the case studies, this research has provided insights into how teams that are practicing innovation engineering embark on a joint exploration journey, and on that journey, they achieve a shared understanding of the problem to solve and one or several satisficing solutions. The findings in this research lead to the answer to the second research question and can be summarized as follows:

- The organization's innovation engineering process should be designed and documented, with a clear start and a clear end,
- Innovation engineering practice should be defined and documented, referring to both the individual skills and team ways of working,
- Two tools are suggested for supporting cohorts to guide innovation engineering without interfering with the team. These tools are the team journey map for team dynamics and social connectedness, and the hunter-gatherer map for team performance and preservation of ambiguity,
- Within a large manufacturing incumbent, the leader responsible for exploration-oriented work, or innovation engineering, must take on a buffer role between the exploitation-oriented and exploration-oriented organizations. Furthermore, it is up to the individual with the buffer role to make sure that innovation engineering is adopted, both as a core process and as a core competency. Findings suggest that this individual is more likely to succeed with this mission if he or she reports to a C-level executive or has continuous interaction with the C-suite in other ways.

These conclusions are based on empirical research and theoretical foundations. Their implementation is expected to enable large manufacturing incumbents to effectively institutionalize, guide, and lead exploration efforts, thus enhancing their innovation capability and competitiveness in the marketplace.
The third research question (RQ3), regarding how to bridge between exploration and exploitation in large manufacturing incumbents, the findings in this research lead to the following proposed answers:
Efforts into bridging between the two needs to be done from the following three directions simultaneously: a) top-down, b) from exploitation-oriented teams to exploration, and c) from exploration-oriented teams to exploitation. For situations when innovation engineering results in conceptual PSS solutions and the organization is product-centric, two bridging approaches

are suggested: a) intentional PSS design and b) standardized solution visualization.

The fourth research question (RQ4) on how bridging between exploration and exploitation can facilitate a large manufacturing incumbent's transition from product-centeredness to product-service system orientation is in this research answered through the following two conclusions:

Infusing organizational ambidexterity throughout the organization requires a top-down cascading mechanism while also making innovation engineering widely understood. This combination will mitigate organizational inertia, bureaucracy, and risk aversion, which otherwise might hinder promising PSS solutions and impede business orientation shift.

New tools and approaches for designing PSS solutions are necessary. The two suggested bridging tools, intentional PSS design, and standardized solution visualization, are two of many potential solutions. With a digiphysical approach to research and development, where both product and contextual data can be utilized from early design through the solution's entire lifecycle, a much more sophisticated design approach can be developed.

This research aims at contributing to the understanding of how large manufacturing incumbents might futureproof themselves. By highlighting innovation engineering as both a process and practice, exploitation-oriented organizations can institutionalize and build expertise in exploration. With a clear strategic intent as well as strategic alignment from the top and throughout the organizational hierarchy, organizational ambidexterity might be infused into large manufacturing incumbents' organizations. The suggested innovation capability framework, the guiding tools to be used by supporting cohorts, and the proposed bridging approaches can provide hands-on support to employees in large manufacturing incumbents on different levels but with a shared mission, to futureproof the company and ensure its longevity.

6.1. Summary of contribution to knowledge and practice

This research contributes to the knowledge domains of engineering design, R&D management, and innovation management. By focusing on the concept of innovation engineering as both a process and a practice of exploration, this research enhances and deepens the understanding of how to build this capability, provide support and guidance, and institutionalize it in large manufacturing incumbents. Additionally, this research contributes to the body of knowledge on innovation capability building with a tested approach based on four components. In terms of bridging exploration and exploitation, the suggested intentional PSS design approach and infusion of ambidexterity are key contributions to knowledge. The research focuses on large manufacturing incumbents with globally dispersed organizations, making it best suited for addressing such multi-layered contexts.

This research provides an enhanced understanding of the necessity and implementation of organizational ambidexterity across all sites, functions, and hierarchical levels. Additionally, the exploration process is decoded through the concept of innovation engineering as both a process and practice, contributing practical insights into the nature of exploration. Tangible tools and approaches are also provided to facilitate the bridging between exploration and exploitation and the shift from products to product service systems (PSS) solutions. Overall, this research contributes to the practice of large manufacturing incumbents by providing tangible tools, recommendations, and examples to enable intentional, responsive, flexible, adaptable, ambidextrous, and future-proof organizations.

6.2. Future research

Coming out of this research, several potential avenues for future research are identified. One of them is conducting empirical studies in different contexts to test the generalizability of the presented results. It would be interesting to explore how the findings could be applied to different industries and settings, such as different sizes of organizations and both private and public sector actors, and certainly multinational corporations in different contexts. Such studies could also help identify potential obstacles or challenges that may arise when implementing the proposed strategies and approaches. Another potential area for future research is innovation engineering, both as the process of conducting explorative work and as the capabilities. Additionally, a following research could explore how organizations can balance exploration and exploitation to maximize innovation outcomes. To further investigate the role of organizational culture, leadership, and structure in building innovation capabilities and fostering ambidexterity within organizations would also be interesting.

Another interesting area for future research is evaluating the effectiveness of the suggested innovation engineering tools in both graduate student courses and in industrial practice. Such research could explore how innovation engineering principles can be integrated into educational curricula to prepare students for future innovation challenges. It could also investigate how organizations can apply innovation engineering to their processes.

Future research could also explore the potential implications of intentional PSS design with an integrated digiphysical perspective for facilitating a shift in business orientation and enhancing collaborative innovation in complex value constellations involving partners from various disciplines and sectors. Researchers could investigate how intentional PSS design approaches can create value for customers by leveraging digital technologies and physical components in an evolutionary tandem, and how they can enable manufacturers to offer a range of innovative integrated services that continuously improve based on use and surrounding conditions. For example, a study could examine how manufacturers can use connectivity, continuous software updates, and artificial intelligence to provide integrated services that are contextually optimized and responsive to customer day-to-day needs.

Moreover, future research could explore how intentional PSS design can enhance collaboration, trust, and co-creation in complex value constellations. One potential avenue for investigation could be the use of a collaborative innovation platform, combined with intentional PSS design, to enable value creation across multiple domains, including technology, business models, and customer experience. This type of research could help organizations of all types, and value constellations, become more agile and innovative, and better prepared to adapt to a rapidly changing world.

Overall, the proposed future research areas have the potential to contribute significantly to the field of innovation engineering and bridge the gap between exploration and exploitation. By investigating intentional PSS design with an integrated digiphysical perspective, researchers can gain new insights into how organizations can become more innovative, agile, and customer-focused, while also creating value for partners and customers in complex value constellations.

Appendix: Short summary for industry practitioners

This chapter is written for you who are working in a large manufacturing incumbent. Your role is either as a leader involved in innovation capability building, or you might be an engineer involved in exploring new ways to solve customer problems. You might have interest in futureproofing the company and you might be open to business model innovation. I summarize the key takeaways from this research as recommendations. This can feel overly simplified, but not to worry, further details are found in earlier chapters, or in conversations with me.

General recommendations

Embrace the fact that your organization is complex and multilayered. Think of it as a very unique burger. The top bun represents C-suite executives who should instigate clear strategic intent and both-and leadership from the top. The bottom bun represents the small group of employees who are focused on and specialized in the exploration-oriented work, i.e., Innovation Engineering process and practice. This work requires competent leadership as the individual giiven the responsibility to strengthen exploration capabilities needs to understand both exploration and exploitation and be willing to take on the buffer role, especially during a build-up time. The crispy and juicy middle layers represent middle management and their teams in different functions and on multiple sites. Here's where most large organizations get complex, multifaceted, and interdependent. It is not possible, nor desireable to separate the different components of the middle from eachother, they are all essential components of what makes the burger a burger. Overcoming challenges in this middle layer is tough due to factors such as organizational inertia, expected as well as actual quarterly financial results, and unexpected events, such as a pandemic, a war, or other disruptions. Futureproofing requires continuous efforts top-down, bottom-up, and across the organization.

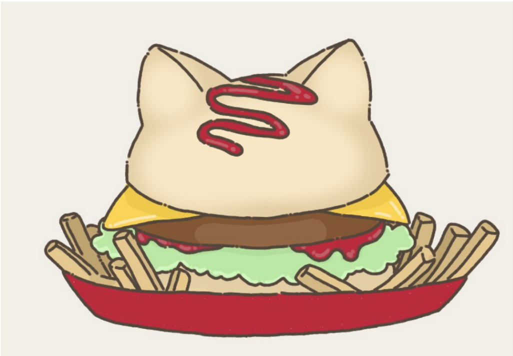


Figure 21. A very unique burger, by Mars Albertsson (2023).

Strengthening your innovation capability

Clearly communicate the need for innovation capability and the expected outcomes of the initiative. The top management must provide a clear strategic intent. Managerial layers across all functions and sites must align strategies. Embrace and leverage the different cultures and conditions of each site, highlighting these differences as strengths that drive market competitiveness and future readiness. Invest in a network of local innovation ambassadors or coaches, providing training locally, collaboration globally, and being supported by local and executive leadership. Encourage sharing of best practices as a means for market competitiveness. Ensure transparency and pedagogic documentation for exploration across the organization. Measure innovation capability using an approach that aligns with the organization's strategic intent and context, provides actionable results, and tracks progress. Start measuring early, using data for nudging and progress tracking.

Innovation Engineering capacity building

Make it clear that innovation engineering is a core competence. Document the innovation engineering process together with the other main processes. Train employees in both the process and the practice, some need competence on a basic level, some need to be the company’s gurus.

Accept that this will take time. You might want to accelerate this establishment by collaborating with academia, where student projects show innovation engineering in practice. A student team can work freely with the project being part of their education, not burdened by a business-driven organization, why this is a resource-efficient way of building understanding.

Bridging exploration and exploitation to enable PSS

Make sure C-suite executives instigate "both-and" leadership by prioritizing both exploration and exploitation. Ensure strategic alignment through all hierarchical layers and across functions and sites, with middle management showing that also exploration is a priority. Set ambiguous and ambitious project goals that promote "zooming out" from physical artifacts, such as improving productivity or reducing CO_2 emissions. Intentional PSS design is useful for the innovation engineering work and can also be an effective bridging tool when documented and transparently shared. Foster explorative collaboration with a partnering customer, with mutual openness, trust, and risk-sharing. Ensure innovation engineering skills are present throughout exploration projects, with domain expertise engaged as needed and preferably time-boxed as they are needed for exploitation work as well. Allow flexibility in resource allocation and have sufficient dedicated budget for exploration. Remove unnecessary barriers for budget spending reporting, bureaucracy, or inflexibility that may lead to premature restrictions and faulty decisions.

“Here’s to the crazy ones. The misfits. The rebels. The troublemakers. The round pegs in the square holes.

The ones who see things differently. They’re not fond of rules. And they have no respect for the status quo. You can quote them, disagree with them, glorify or vilify them.

About the only thing you can’t do is ignore them. Because they change things. They invent. They imagine. They heal. They explore. They create. They inspire. They push the human race forward.

Maybe they have to be crazy.

How else can you stare at an empty canvas and see a work of art? Or sit in silence and hear a song that’s never been written? Or gaze at a red planet and see a laboratory on wheels?

We make tools for these kinds of people.

While some see them as the crazy ones, we see genius. Because the people who are crazy enough to think they can change the world, are the ones who do.”

Apple Inc.

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Paper A

BECOMING AN INNOVATIVE COMPANY: ASSESSING AN ORGANIZATION'S INNOVATION CAPABILITY FROM THE PERSPECTIVE OF A TEAM

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ABSTRACT

Literature points out the need for companies to innovate continuously. Such need requires that companies develop capacities to exploit and improve current work as well as to develop and explore more radical opportunities. This paper is a case study that investigates the innovation capabilities of a multinational manufacturing company by interviewing a group that is mandate to support the development of those capabilities. The data was collected by semi-structured interviews, which were based on the categories of a framework previously developed. The findings speak about the importance of setting clear processes for continuation and implementation of ideas, adequate allocation of resources and management support. The discussion and conclusion are about the importance of the integration of efforts in different organizational levels and some of the future challenges integrating the innovation efforts into a natural way of working.

***Keywords**: Innovation capability, continuous innovation, case-study.*

1. INTRODUCTION

The literature on innovation points out the need to develop the capacity to innovate continuously. Börjesson and Elmquist (2011) affirm that innovation capability is a capacity to develop and seize opportunities, i.e. a company is prepared to innovate whenever possible. Continuous innovation implies placing as much attention to the day-to-day work, maintaining production and incremental improvements, as to the development and exploration of more radical opportunities (Bessant et al. 2005; Boer et al 2006; Boer and Gertsen 2003; Magnusson and Martini 2008). Boer and Gertsen (2003) note the need to simultaneously coordinate between operational excellence and strategic flexibility, what others refer to as the need to simultaneously exploit and explore (Soosay and Hyland 2008, March 1991, Kim and Mauborgne 2004).

One of the challenges to develop innovation capabilities is being able to "develop alternative routines for discontinuous innovations which can sit alongside those for steady state 'do better' innovation" (Bessant et al. 2005). Traditionally, researchers argue that such development happens by the creation of separate companies, projects or teams. However, other researchers suggest integrating both of these aspects within the company capabilities (Lawson and Samson 2001; O'Connor and DeMartino 2006; Bessant et al 2005).

Börjesson and Elmquist (2011) point out that there is little in-depth research about how innovation capabilities are developed in practice. Hence, one of the aims of this paper is to contribute to the research about the development of innovation capabilities in practice. For this reason the paper is based on a case study that explores the current status of the innovation capability within a multinational manufacturing company. The assessment is based on interviews with a group whose mandate is to create context to support the development of innovation capabilities. We want to know: How employees perceive innovation capabilities within their work environment?

2. BACKGROUND

Innovation capabilities are seen by the lenses of the first stage of the MINT Framework and its categories for assessing company's innovation capability (Nilsson et al 2010; Regnell et all 2009). This assessment is not a judgement of whether the company is innovative or not; rather it the perspective of an "innovation team" about the categories that compose innovation capabilities. At this stage the MINT framework considers 6 categories (Fig.1) that are further subdivided:

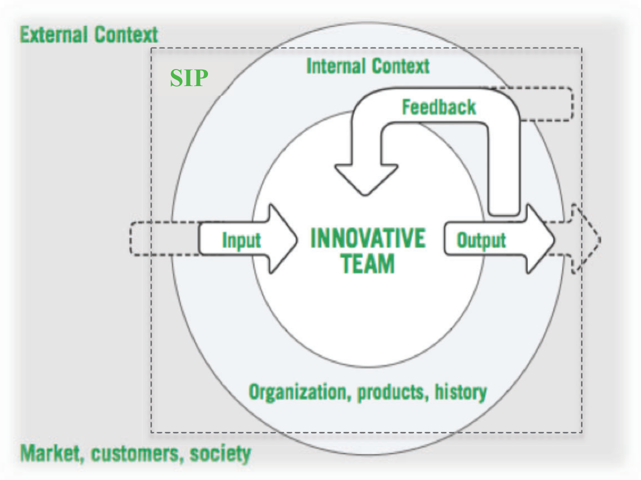

Figure 1 MINT categories adapted from Nilsson et al 2010

1. Strategic Innovation Processes (processes, climate strategy and incentives);
2. Input (resources and innovation task);
3. Output (deliverables, results and effects)
4. Feedback (goal attainment, external and measurement and evaluation);
5. Internal Context (organization surroundings);
6. External Context (user, receiver and stakeholder).

Each category is explained below.

2.1 *STRATEGIC INNOVATION PROCESSES (PROCESSES, CLIMATE STRATEGY AND INCENTIVES)*

Innovative companies have a process for dealing with ideas (Nanda and Singh 2009). There are a number of suggestions about how to define the different phases that compose innovation processes (Gericke & Blessing 2012), however, need finding, idea generation, idea selection, prototyping and implementation seems to be a generic structure that can be unfolded in more detailed phases or simplified. Moreover, Teece (2014 pp.16) points out that innovative companies are able to adjust their processes to promote learning, coordination and reconfiguration of companies resources; hence, they are able to adapt to changing environments, but are also able to shape them.

Innovation climate often comes closer to innovation culture. Some culture can be defined as the underlying values and assumptions in a group or organization (Isaksen & Lauer 2002). Meanwhile climate is the manifested behavior of the culture. In this sense, culture can be subjective if considered at the individual level or objective if considered at the collective perception of the categories that compose culture. The literature suggests a number of categories that compose climate. Ekvall's (1996) model suggests that components of the innovation climate are: challenge, freedom, idea support, dynamism/liveliness, trust/openness, idea time, playfulness/ humor, conflicts, debates, risk taking. Lawson and Samson (2010) also suggest empowered employees, tolerance of ambiguity, and communication as characteristics of a innovative culture and climate.

Incentives are also a common category from a general innovation process (Metz et al 2007; Lawson & Samson 2001). Adequate rewards for innovation are essential to build up innovation in teams (Folkestad & Gonzales 2010), hence the rewards are related to the characteristics necessary for innovation such as risk taking or idea generation (Nanda & Singh 2009).

2.2 Input (resources and innovation task)

The literature suggests that adequate resources, as well as resources that are additional to the minimum required for operation (slack), need to be available. Both, adequate resources and slack, relates to time for ideas and learning, financial resources, equipment, human capital and knowledge (Teece 2014, Metz et al 2007).

An additional input is a clear vision and purpose at the organization and team level, as well as the alignment between the two is considered to support innovation capacities (West & Sacramento 2011; Katzenbach & Smith 2005).

2.3 Output (deliverables and effects)

There are a number of possible outcomes from an innovation process, from the simple incremental to radical improvement to products, services and processes (Crossan & Apaydin 2010). Sawhney et al (2006) suggest that organizations have 12 different areas to innovate such as customer experience, products, brand, platform etc. A team can have deliverables that relate to more than one of those areas. Therefore understanding the deliverables is also mentioned as a relevant capacity from the team level perspective. Katzenbach & Smith (2005) suggest different types of teams according to their deliverables, such as "teams that recommend things", and "teams that run things".

The vision, purpose and tasks need to be translated into goals, which in turn help teams to identify actions and outcomes that are relevant for innovation to happen (Katzenbach & Smith 2005). Agreement on goal, as well and motivating and challenging goals are a characteristic of creative teams (Isaksen & Lauer 2002)

Output also speaks about concrete outcomes not only in terms of offering, but also in terms of learning and changes within roles. If one is to become innovative, roles are also likely to be impacted by experimentation and adapt to new ways of working (Börjesson and Elmquist 2011). One example of such changes is the article from Alexy and Wallin (2013) studying the impact of the adoption of open innovation process in different roles.

2.4 Feedback (goal attainment, external and measurement and evaluation)

Often the metrics used within companies are not useful for innovation. There is a strong focus on financial indicators, and a lack of an overall framework that also allows measuring processes and organizational properties such as flexibility and openness

(Adam et al 2006). In addition, beyond measuring performance, measurement can be used as a tool to promote and support behavior, in opposition to an accounting perspective (Simons 1990). In relation to innovation, it is considered a challenging area because innovation is complex, multidimensional, and unpredictable, which creates specific requirements on what and how to measure (Nilsson et al 2012; Murray & Blackman 2006). Schreyögg and Kliesch (2007) suggest companies need to develop a "capability of monitoring" in order to assess the validity of innovation capabilities in relation to new activities (Börjesson & Elmquist 2011).

Setting up goals is also an essential piece for feedback and measuring systems. Katzenbach & Smith (2005) argue that setting goals and translating them into action helps the team to be accountable, and also it helps to self organize discussing ways to understand purpose and tasks, choose adequate means and follow up progress.

In addition, feedback can be seen in the context of idea generation as idea evaluation. Idea evaluation can hinder creativity; however there are studies that see a positive relationship between feedback in the form of idea evaluation and innovation performance (Nanda and Singh 2009).

2.5 INTERNAL CONTEXT (ORGANIZATIONAL SURROUNDINGS)

This category is close to the strategic innovation processes (SIP) described above. But while the SIP focus on the activities and context that influences the team work, the internal context focuses on the handover and transference of knowledge or outcomes from the innovation team towards possible receivers within the organization. In this sense, innovation climate, abortive capacity and idea management mechanism are "concepts" that are closely related to internal context.

One aspect of the context is that it can "place" demands and expectations for innovation to happen, which impact those who are supposed to work innovatively. These demands are "external" to innovation teams, and they can originate from within the organization, i.e., originate from the internal context as consequence of management style or the innovation climate, as well as from the external context, such as market demands and changes. For the ideation aspect high demands can inhibit creativity but support the implementation of the innovation within the organization (West 2002).

2.6 EXTERNAL CONTEXT (USER, RECEIVER AND STAKEHOLDER)

Engaging openly with external sources is also a common suggestion for building innovation capabilities and innovative teams (West et al 2004). Folkestad and Gonzales (2010) reiterate the importance of a team looking beyond the organizational barriers, and have a outward focus. Such outward focus implicates on searching for needs as well as perspective and technologies also outside the organization or team. Moreover, such external contact is related to input in activities such as need finding as well as feedback and learning are related to the output and outcomes of processes services or product development and implementation.

3. METHODS

The paper is based on a design approach (Blessing & Chackrabarti 2009) not to explore how successful innovative companies have developed their innovative capabilities, but rather to explore the status of capabilities in a real context. In this sense this is a descriptive study of the current reality of the innovation capabilities of an organization that aims to become more innovative. The immediate contribution of the paper is to define specific challenges that companies have when integrating innovation into their daily work. Despite being difficult to generalize the findings, given we are studying only one company, nonetheless, they refer to real challenges. Such results can be used to understand challenges companies might face when trying to refine their innovation processes, as well as, the results can be used as input for comparative case–study.

The data was collected by interviewing 9 employees, who are related to a group that is responsible for supporting the development environment in which innovation capabilities can flourish. The interviews were semi-structured and based on a questionnaire structured in accordance to the categories mentioned in session 2: strategic innovation systems, input, output, feedback, internal and external context.

The interviews were recorded and transcribed. After the transcription the data was analysed in a spread sheet (fig.2). First, each interview was colour coded, and statements were separated in different lines. The colour code and statements were placed in the first and second columns of the spread sheet. In the next column, each quote was tagged in the above-mentioned 6 areas. In the last two columns statements were synthesized and classified as being perceived positive or negatively.

The last step was to classify the synthesized statements according to topics in order to visualize any underlying themes across the different categories. Finally, these themes were settled within the original categories of the mint framework.

	A	B	C	D	E	F
1	Numbers	Text	Mint Categories	Parallel Mint Categories	"+ and -" **Andre**'s Synthesis	"+ and -" **Andre**'s Synthesis
43	113	R:We have technology area plan. I thin you can call innovation plan. It s a long term vision which we believe we could evolve to. I think you can call innovation plan, but can you plan innovation. because if you plan what products one is going to have in 20 year that is based on what we know today. hat is a kind of try to look in the future and try to think how to develop technology wise	FB3: Measurement and Evaluation		"+" innovation plan	"-" innovation cant be used to evaluate long term innovation
44	151	:we measure in no way how good the solution is except for qualitiy and failure when we test the product on the field, but I have seen anything that the new solution should be completely new to the market, never seem before because that is a too high risk.	FB3: Measurement and Evaluation		"+" product is tested for quality and failure on the field	"-" no other way than quality and failure is used to measure a quality of innovation

Figure 2 sample of analysis spread sheet

4. FINDINGS

The findings below represent the perception of the interviewee's about the innovation capabilities categories in which the interview were based. They are organized according the general heading of the capabilities. The emergent themes were: general perception, innovation management and risk management, types of innovation, innovation processes, incentives and acknowledgement, resources, time, goals and assignments, ownership, customer connection, documentation, continuity, implementation and feedback, cross-boundary collaboration, measurements. Because some of the themes are present across the categories they are not presented in a consolidated way, but are integrated into the different categories as needed.

4.1 *STRATEGIC INNOVATION PROCESSES*

The interviewees perceive a clear intention of supporting innovation and wish from top management to improve innovation capabilities. However there are cultural/climate and management issues that are perceived as a barrier. For example, there are many costs associated with innovation. Such costs are perceived as reasonable and often related to quality control, however they reduce the number of viable test and prototypes. The interviewees also point out that the current risk assessment criteria are not conducive for managers to choose innovation. If innovations are going to be evaluated in terms of short-term cost, and comparing the future innovation with current products, it is less likely that innovation is going to be chosen. Developing a business case and ROI for radical and undeveloped ideas was pointed as a challenge.

General perception – The top management intention and support with budgets for exploration projects is perceived positively in relation to the over climate, in some departments respect for ideas that are more radical was mentioned as a negative aspect. Partly the perceived lack of "respect" might originate from the feeling that the culture in general does not support innovativeness. Dealing better with failure was also a point mentioned.

Innovation management – Middle manager is often seen as a barrier for innovation, although interviewees also understand they are under budgetary and time pressure. Their support is essential to get improvements into the products. Different factors promote this situation, the main factors we can deduce from this research are: the manager style, cost associated with innovation, risk management and the pressure to get the work done. According to the interviewees, the drive for reliability and quality can increase the product value, however if not well balanced it can become a misleading criteria for innovation.

Types of innovation – Most of interviewees seem to consider an innovation when an idea has reached the market. It seems that these ideas should have been developed in house. There seem to be a tendency to think of innovation as radical/disruptive, and as technology related. Although data doesn't directly confirm that, most of the examples were connected to technology. Furthermore, considering that the problem solving from daily work requires creativity and innovation, one can assume that when they affirm "we don't work with innovation" means that there is no major breakthrough.

Processes – Overall, the focus on patent and its related processes is clear for the majority of interviewees, although it is said to be bureaucratic, time consuming and does not drive innovation. In addition, there are structures for dealing with ideas beyond the strategic projects decided by "high level managers". One of them is a platform for ideation and dialogue (Benaim et al forthcoming), another are grants for exploration of ideas. Some interviewees claim that there are no forums for ideas, while others perceive the process as just throwing ideas. Furthermore, the request for continuation and implementation of generated ideas (see 4.4 and 4.6) suggests that these processes need to be refined and are still to take roots, and attention to the innovation process is needed.

One factor related to processes is the roles employees play within it. Innovation is perceived to be carried out by some departments more than others. One possible factor for such perception can be due to the perception of innovation as being more related to radical/disruptive technological innovations rather than leaning outcomes, or innovation in other areas rather than technology. Hence, advanced engineering projects are perceived as focus of the innovation efforts. Moreover, a complementary explanation is that innovation is not yet fully integrated into the daily work, therefore, the perception they can only innovate in specific departments and projects.

Incentives – In relation to incentives, salary and monetary is recognized as an incentive, but it does not seem to be a central piece of the puzzle. In general the engineers are self-motivated by the challenge of finding solutions, "beating" competition, and how the clients are satisfied. Just communicating about things might be enough to get them boosted with energy. There seem to be a craving for feedback as well as acknowledgements. People want to feel that what they are doing is considered relevant. That links directly not only to feedback, but also follow through and implementation of the ideas. They also point out that despite there is a technology award, such incentive is too big and smaller incentives are needed.

4.2 INPUT

In relation to resources time is one of the biggest challenges, with very little time for concept development and no slack. The main barrier is that the daily work runs over innovation. Despite that the nature of the "design" work is creative/innovative in itself, there is a feeling that one is just getting things done. The lack of time to think through ideas and concepts creates a feeling that innovation is not well integrated with daily work, it feels like something extra, something that requires more resources. In addition, the risk management culture, testing costs and the pressure on managers to keep on budget and on time seems to add to this perception of lack of resources and lack of time.

In addition, interviewees stated that are few or no resources to work with innovation. The interesting thing is that there are formal resources for advanced engineering and emergent technologies projects. Furthermore, there is a bottom-up process to get ideas evaluated granting money and time. In addition, there seems to be partnerships with academia going on, but some how those don't seem to add the feeling of resources being deployed on the innovation front. One possible explanation/factor is that such feeling is derived from the perception that innovation is not a priority and lack of time in daily routine run over innovation, as well as from the lack of clarity and learning curve of process that is just starting to get in place. Hence, due to daily project pressures, such a process is not appealing.

In relation to goals and assignments, the employees recognize the request and intention from top management to move forward as an innovative company. Many however say that there are no clear goals and therefore their specific assignment related to innovation is not clear. Lack of focus creates a lack of direction for activities, except in R&D projects. One example is the communication about roles and expectations within the company's innovation platform (Benaim et al forthcoming).

This might seem contradictory, but less pre-defined innovation was also an emergent category that relates to input and goals. The finding here is that although focus is important, the perception that real innovation climate does not predict the outcome from the beginning. So there is a balancing between requirements and solutions description. In some instances features such as engines require constant update not only in terms of performance, but also due to policy enforcements. For instance, coping with policy can be a limiting factor for innovation, as it requires a constant narrow focus. Imagine that the forthcoming policy will reduce the acceptable levels of CO_2 emission; a narrow view can be reducing CO_2 emission by improving filter or engine efficiency in order to keep up with policy. However, a broader view of the problem could foster the development of electric engines. Except from advanced engineering projects, engineers feel limited following ways to cope with legislation rather than exploring real design possibilities. Furthermore, requirements and plans also seem to limit innovation. The first, by giving too specific constraints, which can also be interpreted in ways that not always reflect the desired outcome; the second, by the difficulty of predicting what will be novelty before the exploration. In addition, spending resources in catching up with competitors' technology, although it might be necessary on the one hand, on the other limits innovation.

In relation to ownership**,** this category speaks to the perception of those who are "allowed" to innovate and what characteristics are needed to be innovative within the actual context, in a way it relates to the mandate and innovation task individuals and departments have. From the eyes of employees of other departments, while it is good that there are departments and projects working with finding and developing ideas, this seems to give these departments and projects some ownership over the innovative process and take away empowerment from the individuals. Such perception seems to be reinforced by practices like micromanagement, risk management, lack of time and manager support.

From the individual itself, as an interviewee mentioned, "it is a struggle to innovate". It seems that the innovator has to be very determinate and persistent to overcome all the barriers (management support, risk management, time, budget). It happens, but it requires effort on top of the work hours, such as networking and keeping updated with the field.

Finally, a few times the relevance of customer connection was emphasized as well as the point that good innovations have come out of the direct partnership between client/user and designers.

4.3 Output

Documentation was also mentioned as common practice that carries barriers for innovation. The finding here is that the more bureaucratic work around an idea the harder it is to actually develop it; regardless if the innovation in focus is a daily innovation asked by requirements or whether it is a radical idea. Another perception around documentation is that it ends up not being used.

The speed of the innovation cycles came up often, either to ask for implementation of the ideas, or to say that ideas take time to develop and that need to be taken into account. Some interviewee's pointed that the comparison with the software industry may not be adequate because of the different implications of building a product from prototyping, training costs as well as the length which maintenance and spare parts need to be available. The question that remains is an adequate cycle time if innovation is truly incorporated into the company culture? And, can we make the current cycles more effective?

Continuity and Implementation are major problems for harvesting the creativity and sustaining employees drive. Engineers are eager to see ideas becoming products, however they don't feel like ideas are given continuity or implemented. Continuity speaks to the further exploration and incorporation of the ideas into the company's portfolio and products. In a way it is related to functional processes for idea development, adequate feedback, and hand over within the company's internal context. Such relation are explored in the items below.

4.4 Feedback

Interviewees pointes out that the amount of sales, documents from marketing reporting customer feedback and the few innovations that are developed in direct contact with the client (by the design engineer) often provide a good feedback. However, there is a wish to have an increased feedback from the marketing department, customers, managers and the advanced engineering department in general. The lack of feedback kills motivation and discourages innovation because there is no reference to whether the work or the idea was good, or even interesting from a strategic point of view. In this sense, feedback is also requested in the form of continuity and implementation. If the idea within the development process is dis-continued, employees want to understand why, and what are criteria for such decision, and what can they learn from it. If the idea is handed over or implemented into product this is also a required feedback. Regardless whether the answer is positive or negative knowing the outcome of one's effort is a kind of "feedback" that fuels motivation.

There are a few measurements in place such as patent count, but most of them are not adequate to measure the innovation process, nor the value of an innovation especially during its early stages. Patents do not how the innovation efforts. In this sense this can be understood that such measurements do not tell how well one (person team department) works, nor how innovative the offerings become.

The difficulty of evaluating an innovation was mentioned. Despite the solution about what to measure not being available, it is clear that business case and risk assessment are not good measures for evaluating radical ideas or ideas in early phase of conceptualization.

Some interviewees also pointed out that some departments have plans that can be used to assess achievements, however participants also pointed out the difficulty of predicting innovation, especially radical ones.

4.5 Internal Context

Communication of innovative initiatives, collaboration between departments and functions is an issue to be focused on. Employees could benefit from a systemic view to contact similar or complementary initiatives, as well as work with different departments. If an innovative idea has an impact on a different group, it seems difficult get their time and interest to work on or provide feedback about the idea. Part of this difficulty id because each group/departments have their own priorities (and low resources): In addition, the syndrome of "not developed here" seems to be part of the company's culture. There is a perceived need for cross function teams, as well as a way to transfer technologies.

As a positive point Innovation Processes have been developed, however they are not fully functional. This is not surprising given that process and structures are still in development and in an experimental phase. Nonetheless, coaching possibilities and intentions to use such a process get dispersed. It is evident the request for clarity about the submission of ideas, the criteria for evaluation, and the ownership exploration projects and handover is evident, which is on the radar of the “innovation executive manager”. Consequences of lack of clarity of roles and process can make employees afraid that they will get more work if they suggest ideas. One example is the disconnection between the technology working groups and the ideation platform. The first is a group that takes care of ideas and decides on grants for exploration projects, the second is a place for ideation and dialogue. None of the initiatives had a clear process and roles by the time of interviews, nor were they integrated, which increases even more the effort needed to get innovation going.

4.6 External context

A common answer for this element was going back to internal customers, and delivering their outputs to innovation platform, which is the department responsible for integrating the different components into the machine. Moreover, the interviewees would refer to the marketing department as having access to final user, and machine owner. The perspective is that the request and needs would arrive to them as design requirements.

5. Discussion and conclusion

Overall, the one take away is that activities are running in parallel. Although we know the intention is to make innovation part of the daily work, the impressions and the current process feel like a separate activity. That is not surprising since the activities to promote continuous innovation capabilities are in its early stages; however, based on the findings we foresee the main challenges that are related to process for selecting and developing ideas, as well as allocating resources such as money, and employees’ time without over loading them with more work. Another challenge is creating mechanisms for alleviating pressure on middle management allowing them to support ideas and teams. Hence, a few findings that seems to be crucial for the improvement of the innovation capabilities within this case study are: time, refined processes that imply on continuity implementation and feedback, as well as management support.

First, the time pressure in middle management and employees rushes the steps related to innovation processes. Time is of the essence for learning, innovation and flexibility. If workers are busy with their tasks they can't be innovative or deal with unforeseen demands (Lawson 2001) and opportunities. Alkpan et al 2010 found no correlation between free-time and innovative performance, however the main point is that time resource is not about open-ended time, on the contrary it is time for innovation, such as time for reflexivity (West et all 2004) or for concept development. Therefore, the open questions here are more likely to be: if individual and teams were given time, would they have the drive, and would they know how to use their time in order to create conditions that are conducive for innovations? In this sense time has two perspectives: one perspective allocating time as a management practice considering as input for teams; the second perspective is the proper use of time by individuals and within teams and projects.

Beyond time, management support is an area for further attention and improvements. Management support increases innovative performance (Alpkan et al 2010). In this particular case, despite the strategic intent of top management being clear, such intent needs to be translated into managerial actions that support innovative ideas, i.e., the company needs to be able to prioritize innovation (Björkdahl & Börjesson 2012). Such support can be in terms of experimentation, exploration of ideas and risk taking. Baer and Oldham (2006) find that supporting creativity and individual openness to experience have a significant moderating role in relation to the capacity to be creative in time pressure constraints. In situation with no support performance tends to go down under time pressure; meanwhile in situations with support performances increases before it reaches a pike and goes down. Such relationship points out to the importance of adequate time, as well as the relevance of management support.

The final aspect is the need for a refined innovation process. Björkdahl & Börjesson (2012) point out that implementation and idea management are capabilities needed for innovation. Within the findings we can see a clear request for the improvement of such capabilities. There is a lot of intrinsic motivation and the open question is: how to design the adequate outlets so the motivation can be translated from insight and creativity towards implementation? In addition to process to get ideas moving, refined innovation processes also include adequate forms of task assessment, feedback and measurements structures that help to evaluate and learn from the innovation efforts in teams beyond the classical financial and outcomes measurements.

Finally, it is also clear that the work for developing innovation capabilities is double-sided, and it is of importance to think in different levels and in an integrated manner. It seems that if we are to move beyond skunk work and best guesses, into a form of organization that consciously uses its processes to continuously develop innovation, one is ought to think about the interface between the capabilities within the different levels: organizational, team and individual level. Individuals and teams need to learn how to use innovation processes in their daily work, as well as in parallel projects. At the same time the organizational support and clear pathways to promote idea development needs to be in place to support the team. Tackling individual and team issues without organizational support is like asking for a soccer team to play in a baseball field; Developing organizational structures without and integrating teams is like developing bridges without access ramps; it is possible to live with both situations but they make life a lot harder.

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Paper B

1 INTRODUCTION

Companies recognize the importance of becoming innovative to remain competitive on a global market. A great deal of attention has been put on developing innovation capabilities, which is the ability to act upon innovation opportunities in two ways: on the one hand, exploring new avenues for products, markets and offerings. On the other hand, improving current offerings and operations (Björkdahl and Börjesson 2012; Boer et al 2001). These two ways are often called exploration and exploitation, or organizational ambidexterity (Kim and Mauborgne 2004; Nagji and Tuff 2012).

While aiming to perform and integrate exploitation and exploration activities into daily work, one might wonder if the ongoing activities are taking the company in the right direction, i.e., "How do we know we are making progress?" and "Are we really becoming more innovative?" Such questions reveal the need for an innovation performance measuring system, simply put it asks for Innovation KPIs (Key Performance Indicators). This paper explores the implementation of an innovation metric system within a case company.

1.1 Context

Why would a company ask for innovation metrics? In this particular case the original request was to find one specific metric that would tell the company whether they were more or less innovative than their competitors. Several benchmarking studies and internal investigations were performed before the decision was made to not look at the competition or scientific data analysis, but instead pilot a metric system that corresponds to all the crucial factors to secure innovative capability and work with the stepwise improvement based on the assessment results. The work was initiated in 2009 and during 2014 two pilot assessments were performed.

Within this particular case study, one of the motivations to working with innovation, beyond the general need of becoming innovative was the insight that there is a vast innovative potential to tap within employees. Many employees, not only within R&D, have a passion for working with innovative products and a bottom-up approach allows to complement and challenge innovative strategies by the identification of opportunities that otherwise would have been lost. If it is to have an impact, such an integrated approach of innovation requires pathways that let the creativity flow from ideation to implementation. The case company has already started working on such pathways (Benaim et al 2014a), but in those early stages they were still unsure whether or not they were actually creating the conditions for being innovative.

In large companies innovation is often directed to R&D departments. This is a classical divide in which companies work as if they had two separate entities, one working on production and the other on innovation and NPD. However, innovation capabilities can also be thought of as complementary to daily work, for example, by setting aside a specific work space and time to innovate in between the daily routine, or by being expected to innovate within it (Lawson and Samson 2001, Lund 2014).

In addition, many companies are dominated by a risk-averse, short-term focused and bureaucratic culture that makes it difficult to drive semi-radical and radical innovation, while small incremental innovation steps are often quite easy to bring forward (Assink 2001). Having a systematic measurement system in place is a way to raise awareness, and drive and monitor progress beyond the incremental innovation space. Moreover, companies with long development cycles have challenges in terms of measuring innovation according to output or outcomes. First, not all outputs will be successful outcomes in the market. Innovation related work is iterative and learning from failure is a natural part of innovation (Elmquist and Le Masson 2009; Sarasvathy 2001). Second, within long development cycles it is not useful to wait until the product is industrialized to determine whether or not the team was working in an innovative way. Third, in large physical artifact-based manufacturing companies it is hard to work with beta releases, as is commonplace in the software industry. Further, manufacturing companies cannot easily discontinue a product without facing consequences for several years. Once the product is in the market, the company is bound to offer maintenance and spare parts for typically about 10-15 years.

Therefore, an innovation measuring system that allows the company to see whether the conditions for innovation are being met is expected to be a way to drive the necessary changes in the organization and continuously strengthen the innovative capability.

1.2 Challenges of Implementing Metrics for Innovation

Innovation performance measurement has a positive impact on innovation capabilities by fostering new ideas, offerings and working routines (Saunila 2014). It can also help to diagnose, motivate, promote learning and strategy implementation related to innovation (Chiesa et al 2009; Godener and Söderquist 2004). However, it is rare to find articles about the process of implementation and its hurdles (Bourne et al 2003). Currently, companies are unsatisfied with their performance innovation system (Dewagan and Godse 2014). Within the case company the innovation related measurements do not lead to innovation (Benaim et al 2014b). Although the importance of innovation measurement systems is recognized by the literature, its implementation is not as simple as it seems. A current challenge is to agree about what to measure and how to make it practical (Nilsson and Ritzén 2014).

A few challenges are presented when implementing metric system. There is a natural NPD bias when selecting measures. This bias can be counterbalanced by looking at categories such as flexibility or innovation structures (Adams et all 2006). Another challenge is the use of the metric system to evaluate ideas too early, i.e., without the proper exploration it will be hard to define the potential of certain ideas (Langdom, 2008). In addition, people can feel limited in their creativity or that the metric system is a bureaucratic exercise (Chiesa et al 2009; Saunila 2014), which undermines the benefits of metric systems. Some of the practical challenges relate to the general evaluation and interpretation of the data retrieved (Nilsson and Ritzén 2014; Neely et al 2000; Bourne 2003). Another challenge is that the results itself can be merely informative, however people need to take action and know how to use the results of the evaluation (Stufflebeam and Shinkfield 2007). Other challenges with implementing measurement system are presented when: there is a disconnection between strategy and department or teams goals; strategy is disconnected from resource allocation; feedback is tactical instead of strategic; there is resistance to change (Bourne et al 2003).

One aspect to point out is that the frameworks often focus on the organizational level or are intended for innovation management. However, innovation in R&D is developed within teams (Zedtwitz et al 2014). From the innovation climate perspective Anderson and West (1998) suggest that the appropriate level of climate analysis is the proximal group because it is unlikely that a shared climate exist at organizational level. Therefore, we explore the team perspective for this measurement work.

For the reasons mention above this paper explores the question: How to develop and implement an innovation measuring system?

2 METHODS

The methodology is based on design research (Blessing and Chakrabarti 2009) and the paper is a prescriptive study that focuses on the implementation of a measurement system in its early stages of testing. Therefore, concrete use situations and challenges related to the implementation framework need to be identified as they emerge. For this reason, the research requires a qualitative approach, hence the use of design research guided by a participatory action research approach used within a case study (Bryman 2008;Yin 2009; Whyte 1989; Coughlan and Coghlan 2002).

The company case is a multinational manufacturing company developing heavy machinery. The reserachers worked with project and executive managers as informants and partners, as well as with a team called iCoaches. The team's mandate is to support the development of innovation capabilities and the implementation and testing of the measuring system. Since it is a single case, the findings are not generalizable but they indicate possible real uses and challenges of measurement implementation.

The method used to guide the system implementation is called Measuring Innovation in Teams (MINT) (Nilsson et al 2010), which is a research-based framework that parallels the steps and areas suggested by literature as explained in section three. Overall, this paper draws its findings from the activities related to selection and refinement of metrics, and their implementation and use.

The implementation and results of the early steps of the measurement process were described by Benaim et al (2014b), which resulted in a picture of innovation capability. The validation of the initial picture and brainstorming of possible innovation metrics were explored through six workshops, involving 120 persons. The workshops involved iCoaches and ground employees from different departments since they were the target group. The suggested indicators were collected and listed. Afterwards, duplicates were merged and language refined. The selection was done in interaction with department members. For the metric implementation data was gathered by survey and direct input when applicable.

In addition to field notes, participant observation and the results documented during the workshops, the research data was collected by a survey that asked about the selection developed and whether the results were sufficient or useful to understand how the results impacted each department. A semi-structured interview followed in order to explore the survey results. In total, nine participants replied to the survey and five were interviewed, those numbers compose 50% of the teams involved in conducting the implementation. After the second round of measurement the results were discussed during a workshop with the implementation group (iCoaches) and the managers. Participants insights during and results from the workshop, such as changes in measures, implementation practices also support the findings described below. Complementary interviews were conducted with the executive manager in order to get more insights related to implementation challenges and general learnings.

3 THEORETICAL BACKGROUND IN INNOVATION MEASUREMENT

This section introduces theory and main elements related to innovation measurement systems. When talking about performance measurement from a managerial perspective, Chiesa et al (2009) list 7 objectives that are clustered in three main categories; diagnostic, motivational and interactive (learning and coordinating). In addition, measurement systems can be used to correct initiatives and implement strategy (Chiesa et al 2009; Godener and Söderquist 2004).

When it comes down to becoming innovative, what are the aspects that one should consider to measure? The suggestions are numerous (Björkdahl and Börjesson 2012; Adams et al 2006; Langdon 2008). Despite that the frameworks and categorizations have differences and nuances particular to each framework and its background, it is possible to find common elements. Often these elements are broken down in smaller subtopics until there is a (set of) indicator(s). For example, Adams et al (2006) in their literature review synthesize seven general categories and related subcategories: Inputs (people, physical and financial resources and tools), Knowledge management (idea generation, knowledge repository and information flows), Innovation strategy (strategic orientation and strategic leadership) Organization structure and culture, Portfolio management (risk and return), Project management (project efficiency, tools, communications and collaboration), and Commercialization (market research, market testing, marketing and sales).

3.1 What to measure in teams

When considering the team level the categories mentioned above can still be useful. However, what are the categories that are specific to team innovativeness? Some authors explore team innovation by relating it to team performance (Bain et all 2001; Sivasubramanian et al 2012; Hoegl and Gemuenden 2001). Performance is composed of concepts like efficiency and efficacy, and sometimes it includes speed to market. Efficiency relates to how well a team can deliver on budget and on time, and the efficacy relates to whether a team delivers what is expected of them (Hoegl and Gemuenden 2001). This relation is intermediated by teamwork quality, which is a construct that involves elements such as group cohesion, balance of member contributions, communication and coordination of activities (Hoegl and Gemuenden 2001). It can be argued that teams that have a high teamwork quality have a better performance; therefore they have a positive impact within innovation projects (Hoegl and Gemuenden 2001).

Another way to relate team performance and team innovation is through the concept of team climate. Weis et al (2011) find a positive relationship between team performance and innovation climate in resource-limited projects. Anderson and West (1998) outline the team climate for innovation in four factors: Vision, Participation safety, Task Orientation and Support for innovation, and later on adding reflexivity (West 2002). Innovation climate is also mentioned by Isaksen and Lauer (2002), where the authors suggest climate categories such as: challenge and involvement; freedom: trust and openness; idea time; playfulness and humor; conflict; idea support and risk taking. In addition, at the team level elements such as psychological safety and team diversity, among others, come into play (Isaksen and Lauer 2002; West 2002).

One aspect to take note of is that different kinds of teams have different correlations with innovation climate and, therefore, a particular climate characteristic may have a different correlation with innovation and performance depending on which kind of team it is measured in. For example, on the one hand, research teams had a positive correlation between elements like task orientation and support in relation to innovation and performance. Meanwhile, NPD teams had a positive correlation for goal

clarity and attainability of objectives (Bain et al 2001).
In a literature review about predictors of team level innovation, Hülsheger et al (2009) looked at team innovation in terms of input and process predictors. In the input category, the authors found a weak, but positive relation between traditional characteristics such as team size, diversity, team longevity. Also, they found a strong correlation between task and goal interdependence. The authors also found a strong relationship to the majority of the process predictors (Vision, Task orientation, Internal and external communication, support for innovation), a weak relationship for participation safety and a low relationship for task and relationship conflict.
A number of papers talk about individual characteristics and their implication on teams (Chen et al 2013). Some of them relate to how different cognitive styles influence teamwork (Miron-Spektor et al 2011), which may shed light on team composition indicators or possible actions around one aspect of team diversity. Openness is anther individual/group characteristic that can influence a team (Davison and Blackman 2005)
Another perspective is considering the innovation process at the team level. An innovation process has a number of stages (Langdon 2008; Gericke and Blessing 2012; Dewanga and Godse 2014) that could be used to measure team innovation providing timely assessment and feedback. It is important to understand what happens within the process, because each phase of the innovation process has its particular needs (Dewanga and Godse 2014; Langdon 2008). This perspective brings questions about how to measure the effectiveness of activities related to opportunity identification and analysis, as well as idea generation and selection.
At the team-level, all of these frameworks involve identifying antecedents, predictors and moderators, however the frameworks are not relating these characteristics to measuring innovation in teams. Furthermore, when it comes to measuring frameworks it seems that they are developed to follow up on results, or used to pinpoint the categories that should be explored without explaining how. One perspective we take in this work is that we aim to develop an innovation measurement system that includes ways to support teams to understand their context and to reflect on next steps.

3.2 How to measure?

Performance measures have been developing to go beyond audit and financial control measures. In its evolution, a number of frameworks have been developed that are useful to provide categories that are relevant to performance (Bourne et al 2003). The choice of an appropriate R&D measurement metric depends on the user's needs in terms of comprehensiveness of measurement, type of R&D being measured, available data and amount of effort the user can afford to allocate to the exercise (Adams et al 2006). That implies that innovation measuring systems need to be adapted to their context and possibilities (Bain et al 2001). So how to start?
We have synthesized five steps from the literature. The first step is: Choosing the approach. There are three primary ways of designing a measurement system (Bourne et al 2003). One is need-led, in which stakeholders and customer needs are put into focus. The second one is audit-led, in which a bottom up approach identifies the current status and needs challenging the status quo. The third is a model approach in which a model is used to prescribe the important elements to be measured. Another distinction is between a consultant-led and a facilitator-led approach. In the first, the consultant does most of the implementation, analysis and "follow up" work. In the second, the work is conducted more by the management (and team members) in collaboration with the consultant in a facilitating role.
The second step relates to the Set-up of measurement system. The alignment of the measurements to strategy is often mentioned as a relevant aspect (Neely et al 2000) Furthermore, for measurement to provide its potential benefit, staff needs to be involved in its design and implementation (Meyer, 1994; Hallgren, 2009). Bourne et al (2005) conclude that engagement in innovation performance provides a positive impact. An interactive use of measurement, where managers personally involve themselves in a frequent analysis dialogue and knowledge-sharing throughout the organization, needs to be encouraged (Simons, 1990; Bourne et al 2005; Nilsson and Ritzén 2014 p.185). Russ-eft and Preskill (2009) have suggested that an evaluation is likely to be used when: a) the intended use of evaluation is identified and planned at the beginning, b) the intended users of the evaluation are identified and prioritized, and c) stakeholders are involved in the process of evaluating.
The third step is about Identifying and using indicators. Integrate different classes of indicators is a strength of measurements systems (Neely et all 2000). Janssen et al (2007) find that the mix of objective and subjective indicators help to increase the conceptual uses of the performance

measurements, i.e. the increase the knowledge base used to support learning processes. One way to think about indicators is to connect them to the activities and outputs related to the innovation process itself. Dewagan and Godse (2014) suggest that innovation performance measurement systems have to support the identification of key KPI according to appropriate innovation dimensions. The distinction between results indicators (also know as lagging or past indicators) and indicators that determinants of results (leading or future indicators) (Neely et al 2000; Parmenter 2010). The former focus on diagnose and access performance. The latter focus on planning activities (Parmenter 2010).
The fourth step is: Data gathering, analysis and report. When analyzing how high performing units behave in comparison to average performing, Bourne et al (2005) find that high performing units gather data from different sources rather than only from the measurement system. For example, through observation in meetings and attention to dialogue and other interactions. In addition, communicating and reflecting about the results consistently (Russ-eft and Preskill 2009) is part of this step. "In high-performing business units, the simple control approach was used to verify performance at the end of the period, but the main drive for performance came from continual interaction with the performance data" (Bourne et all 2005). Therefore, in order to make the maximum out of measuring systems, active and continual communication, as well as, observation and interaction to check the information described on the system is a helpful practice. Within the case study an software “app” was used to display the gathered results electronically.
Finally, the fifth step is to take Actions and Re-evaluate measurement system. The measurement work doesn´t stop with reporting; Evaluating further needed actions is a next step. In high effective units action is taken according to the understanding of the problem, and it consider also multiple aspect of importance beyond the company targets (Bourne 2005). Moreover, measurement should be periodically re-evaluated and obsolete measurements deleted (Neely et al 2000).
Within the case study presented on this paper, the implementation and testing of the measurement system was based on the MINT Framework in an audit led way, with some characteristics of a model approach. Practically, it means that the implementation of MINT involves assessing and developing a snap shot of the current innovation capabilities, communicating the results and deciding on short and long-term goals and related measures, that will challenge the status quo, as well as, aligning the work with strategic intent and the envisioned ways of working more innovatively. The framework also considers that the indicators are dynamic and context specific (Nelly et all 2000). It includes several dimensions such as process, climate and outcome measures. However, the implementation process is not limited to these categories.

4 FINDINGS AND DISCUSSION

This section has reflections and observations about the implementation process trying to outline some of the implications. We highlight metric selection, the purpose and use of indicators, as well as, the role of leadership and empowerment. In addition, we also highlight a few other main challenges.

4.1 Metric selection

Overall 3 approaches to metric selection were identified. Some of the participants took a more experimental approach. 1) Some implementation team members pointed out that at this stage the implementation was seen as a test, and having one measurement was better than none. The idea was to practice and implement the measurement system and keep refining the metric. 2) Others suggested they have put some thought into it, and have considered which information would be relevant for them to know. 3) A few said it was difficult and their main question was how to make sure that the indicators give meaningful and desired result. We suggest that a balance between the first two approaches (test and relevance) is adequate. Trying to find the perfect indicator is difficult and can delay implementation. Overall, most participants were satisfied with their metrics. Some mentioned that some insufficiency was due to the low number of responses, and that gathering data from manager gives a small number of responses and it does not represent the ground level. The learning here is to remember to keep the connection to working levels.

4.2 Uses of the indicators

Four uses of the indicators were identified: 1) **To implement strategy - Promote a behavior** - A participant used the metrics to keep themselves in “check”, reminding them to run the activities related to it. It is a drive force, "it keeps me going". It also helped to see whether the goals were achieved. Finally, it also supports manager to understand the role of iCoach and see progress. In addition by doing the proposed activity they were able to identify other challenges and learn about their assumptions. "We thought it would be easy to set small investigation –even if we had financing, we have not as much time". 2) **To diagnose - Monitor trend** – Some metrics were used to follow up activities, others to confirm an impression/perceived trend. In this case metrics were used to monitor an aspect that might be potentially risky to have low. For example, the department that selected a indicator like this has the impression that as time goes by there are less resources for need-finding and general external input. The idea here is to verify whether this impression is true, and raise a flag, if the trend is confirmed. 3) **To learn by experimenting with metric system** – Some of the participants were really taking the exercise as an opportunity to test working with measurement system (as pointed out in section 4.2). Here the approach is "lets try to use this opportunity and see whether we can make it work for us". 4) **To reflect on practice**: Another experimental learning aspect happened with the sharing and comparison of the results. During the first assessment despite participants looked mainly to their own scores. After the second assessment, a workshop was conducted for participants to debrief the results. Since in this case the indicators and scales were the same for all groups comparison was easy. A meaningful conversation started about the behaviors that lead to those particular results. Participants had a natural interest in those behaviors related to high and low scores.

4.2.1 The innovation indicator - small purposes and sufficient measure

Participants questioned to what extent an indicator can tell them how innovative they are. Indeed, most measures cannot answer this. Often they can only tell how one is performing in relation to one aspect that is relevant for being innovative. Hence, the importance of having multiple, small and specific purpose for the selected indicator, which should be related to a specific context.

In addition, a few interviewees reported that results were better than they expected, but still they didn't feel like they were being innovative. This then opened questions about what is a good reference point and sufficient target: "Does it mean that we are performing well or that we had low expectations?"

4.3 Metrics and indicators content

The metrics content selected by the teams and departments in focus related to time for exploring ideas, costumer and external connections, and climate and management support according to their needs as reported by Benaim et al (2014b). Some examples are metrics related to unplanned time, number of customer visit or number of cross-function meetings. These metrics are related to climate and contingent aspects of innovation.

Metrics connected to the idea management platform (Benaim et al 2014a) focused on number of ideas and the idea's development stages (gates) within the platform. One indicator was selected to track the formation of groups to rapidly explore ideas. Attention was also placed on measuring the spread and awareness about the innovation channels among employees. For instance, a metric asked about the clarity of the innovation process, and whether employees knew where to look for clarification. Output measures, such as number of new features incorporated in products, and articles published were also measured. Such indicators start to address process related dimensions.

There is a strong selection of indictors around innovation budget distribution, as well as, indicators for number of projects dealing with a higher percentage of innovative features; a few indicators about the alignment between project and strategy were selected. These indicators can speak to portfolio and strategy alignment.

The focus on general and higher level indicators that focus on department or organizational level is noticeable; such change is discussed in section 4.5. So far, only two measurements were performed, and a few uses could be outlined (see 4.2), however, little can be concluded about the impact of the selected metrics. The impacts and changes promoted by the use of indicators as well as the changes in the indicators themselves should be followed in a more detailed and longer study, in which the relation to innovation capabilities should be in focus. Up to the second measurement small changes were made to the wording of the indicators to achieve clarity and a more standard set between departments was selected to allow comparison.

4.4 Leadership and Empowerment

The literature quite often mentions leadership and empowerment as an enabling factor for teams to perform. In the case company, this is also noticeable in the amount of work that management and academic partners do behind the scenes to create the setting. They are in constant interaction with top management clarifying questions, reporting progress and making the overall case for innovation and its measurement. The metric implementation management team also played an important role creating psychological safety and empowerment within the team. One example is in the last workshop when participants were directing their questions to the executive manager regarding what their task and deliverable was. Participants were asking what management expects from them. The reply was "what is it that you want to tell the management". Despite that it has been mentioned a number of times that the indicators are supposed to be "what is relevant for the team" they still needed clear leadership and empowerment. Moreover, the project management is also important given the physical distance between participants and the little time they have in their stretched routines. It helps to keep the dynamic and timing going creating the space for measurement and discussion to happen.

4.5 Challenges

We could identify at least 3 challenges selecting and implementing the measurements in this case. The organizational level in focus, legitimation of the exercise, and the use of the visualization tool. In relation to the level in focus: The measurement system was going to be implemented at the project team level; however, executive management changed this orientation to department level. The main reason was that employees work in several different projects on several different sites. Therefore, measuring project teams would become very complex and scattered; some teams are the same for weeks and others are for some years. Some teams are small, co-located and focused, while others have many team members across the globe. In addition, departments are led by line managers that are reporting to directors and the directors to top management. By having the assessment on department level it is possible to get hold of the departmental working climate and one can see how well line managers are encouraging their employees to think outside the box and look for new solutions. The frequency of measuring also supported the level change since measuring something two times per year would not make a difference for most of the teams. Open questions for further research are: Is it enough to have metrics on department level? And, is it actually impractical to measure teams?

In addition, the multiple goals and responsibilities of the supporting group might have been a problem in defining the focus. From being a support group doing activities to promote innovation climate, they became responsible to promote and monitor activities on the idea management platform. At the same time they are also responsible for measuring their departments, on top of their design-engineer work. Within such a broad scope all measurement seemed to make sense, and group boundaries got blurred. Perhaps a clear focus on defining the team boundaries and specific purpose could have been helpful. It is interesting to note that the product planning department has overall and more organization oriented measurements. The responsible reported they reached a personal conclusion that very few indicators would say how innovative they are. One example of such an indicator is number of features adopted into products. In fact that conclusion might be true and relevant for their level of measurements, it shows a reflection and understanding of their innovative goals. However, other groups/departments might require different indicators that are more closely related to their work.

Legitimacy and engagement of management was also a challenge is some cases. Despite of some strong support of members in top management, other would not see the exercise as a priority or relevant. The same was true for the layer of management underneath, which sometimes was required join meeting with top management to show that the initiative was supported. In addition, managers would seem to be more inclined to support the exercise according to position of their managers. This is another reason to move the responsibility of measures a few layers above project teams.

Finally, in relation to sharing information, very few used the tool support to do their report, and the input on the app was done because it was "mandatory". Challenges with the software were not surprising; in a workshop participants pointed out that more training and a few adjustments in the app would have done the trick. Some of the challenges of the app were described as: a) Frequent app crash, b) Visualization of correct quarter and year was not intuitive - One had to be careful to display the right time frame, c) The tool was not ready to use - wi-fi connection and log-in problems prevented immediate access, d) Infrequent use makes hard to remember how to use it, e) Aggregation on hierarchical layer had problems. Participants used their own spreadsheet to follow up, because it allowed making notes and other details next to the data that relate to a particular result.

Results of the implementation were shared with managers. In some cases data from two departments were gathered together, managers presented with the country result asked to have beyond the country data, the specific of their departments. Their reaction was to take in the information. And beyond that a few asked for the next steps. A question for exploration is: How to define and act on those steps?

CONCLUSION

The uses of indicators show potential for the metric system to achieve its function. In terms of practical implications our findings reinforce the need to select smaller purposes for the measurement. There is an indication for the need to hold more than one level at a time, making metrics relevant for the teams, as well as at the management level. Regarding implementation, strong leadership and dialogical skills are key within large companies to engage and overcome resistance to change, including political issues are often a big factor. Engagement of managers proved was also a stepping stone for the implementation to happen. However, it seems that one cannot wait to have a buy-in and that have something on the ground is a way to secure its continuity. The next steps are to consolidate the groups being measured, and explore how these indicators can be reflected into action. Further research could explore the contents of the metrics and its rationale and implications, as well as, whether the measurement actually promoted insights and behavioural changes that impact the ambidexterity in terms of innovation process and climate. Further research can also explore whether team innovation metrics should be developed after or in parallel to an organizational level approach.

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Paper C

Unlocking the full value of a corporate innovation hub

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Abstract: This paper covers research about how Corporate Innovation Hubs, CIHs, in Silicon Valley are managed and supported by their corporate motherships and how their likelihood of success can be increased by conscious and proactive management and support. To embrace the cultural difference as a competitive advantage and learning experience is important. Clear intentions, expectations, team constellation, reporting level and finding the right individual as head of the CIH are identified as crucial factors to consider.

Keywords: Corporate Innovation Hubs; Silicon Valley culture; Innovation outposts; Startups; Innovation ecosystem; autonomy; Emerging technologies; organizational intent; outcome expectations.

1 Introduction

Large mature, incumbents have since the 1970s (Hiltzik, 1999) established explorative presence, such as research, technology scouting, and innovation centers in Silicon Valley. The region is recognized as the world's strongest innovation economy (Startup_Genome_LLC, 2019) with a high concentration of skilled, motivated talents and is the birthplace of many successful electronics and software-based firms such as Apple, Google, Tesla, Intel, Oracle, eBay and Intuit (Berlin, 2017).

Corporate Innovation Hubs, CIHs, or "Innovation Outposts" in Silicon Valley are expected by the corporate headquarter, or the "mothership", to tap into the innovation ecosystem and generate new research, ideas, concepts, and technology (Berger & Brem, 2016) as well as recruit talents.

For two years, the lead author was preparing for, establishing, and operating a CIH in Silicon Valley. Early in the process when visiting and learning from existing CIHs, the following questions were raised:

1. Do the corporates that establish CIHs in Silicon Valley have clear intentions with and expectations on their CIHs?
2. How are the CIHs established, operated, managed, and supported?

While working on establishing the new CIH, the lead author continued to explore those questions and added one:

3. Can insights from existing CIHs be utilized as information to increase the likelihood of success for new CIHs, and CIHs in need of realignment?

2 The Silicon Valley culture

Silicon Valley is a region that spreads from Santa Clara County in the south to San Mateo County in the north, on the peninsula south of San Francisco in California. This "habitat" is known to have everything a technology startup needs to survive and thrive and have grown organically since the 1960s (Berlin, 2017). Citizens, firms, and institutions are benefiting from the geographical proximity, and the cognitive, institutional, and social proximity that this innovation ecosystem fosters (Balland, et al., 2015).

The region's company culture has historically been different from traditional company culture (see Table 1), and even if the below comparison is no longer that regionally distinguishable, it used to be what formed the Silicon Valley culture.

Table 1 Traditional company culture vs. Silicon Valley company culture

Traditional	*Silicon Valley*
Hierarchical	Flat, competence matters most
Formality	Transparency, decisions made quickly and easily changed
Stability	Fluidity and speed, on all levels
Self-sufficiency	Collaboration
Confidentiality	Openness

Source: (Saxenian, 1994)

The region has also fostered its typical entrepreneurial characteristics (Lee, et al., 2000):

- rapid pace and "invent-the-future" orientation,
- ability to create rich connections to other people,
- tendency to share ideas openly with "the valley" people, including competitors - knowing that you cannot succeed on your own, cooperating with a direct competitor is not unusual,
- focus, passion, emotional intensity – a personality trait that is typical for entrepreneurs in the valley, and
- connectedness, far beyond what is necessary for their business, including local government, schools, civic associations.

The main author's experience is that Silicon Valley offers more than presence in the USA, it offers a global presence since the region attracts entrepreneurs, investors, talents, collaborators, researchers and students from all over the world. The Silicon Valley culture leads to insights and collaboration opportunities at a higher speed and with a higher level of competence than in most other regions of the world. Therefore, a strong and solid presence in the SF Bay Area can be enough for a corporation looking to strengthen its technology exploration and startup collaboration portfolio.

The pay-it-forward culture

A very busy manager of a waste management facility in Alameda County was asked by the main author to host a group of students for a study visit. Not only did he arrange that visit but also connected them with other relevant people, sent over material afterwards, and participated in their final presentation at the school. That is how the "pay-it-forward" culture (Blank, 2011) works and it is a strong cultural marker for the region. The Silicon Valley citizen is a problem solver, with appetite for complex, wicked problems (Rittel & Webber, 1973) and opportunities to change the world. In this fast-moving, dynamic, technology- and science-embracing, competitive, and sometimes harsh environment there is also a comforting bias towards helping each other.

Another descriptive example of this culture comes from what William Cockayne, a well-established, well-connected Silicon Valley entrepreneur and scholar, provided as guiding principle to the main author, when initiating the work to establish a CIH, in 2018:

> "Whatever you do here, make sure that the Valley wins. Then there is at least a chance that you will be successful."

For the main author it seems like even the sun makes a difference as many connections and collaborations begin with coffee shop talks and leisure walks. The Valley is full of resourceful, supportive citizens that generously provide advice, connections, and other support to everyone who also pays it forward, and failing to do so might find you battling on your own.

3 Understanding Corporate Innovation Hubs in Silicon Valley

CIHs are expected to be the bridge between the mothership and Silicon Valley and generate value for the larger organization. Much of this value is knowledge transfer outside in, but equally important is the knowledge transfer in the other direction as strong relations built on mutual trust is key to successful partnerships. Two major challenges with this transfer are the "Not-Invented-Here" and the "Not-Sold-Here" problems, often preventing the CIH from being that bridge. There are ways for the corporates to overcome those challenges, and the main author collaborated with two M.Sc. students to explore this in their thesis work. Insights include an understanding of causes, consequences, and suggested mitigation actions; such as alignment of objectives between the mothership, the CIH, and the startup and creation of a robust and trustful knowledge-sharing environment (Amann & Granström, 2019).

Steve Blank writes in his blog post (Blank, 2015) about "Innovation Outposts" that most of them are:

> "…at best another form of innovation theater – they make a large company feel like they're innovating, but very few of these outposts change a company's product direction and fewer impact their bottom line."

Corporates that are establishing CIHs are according to Blank doing it to sense and/or to respond to technology shifts. Sensing typically depicts the technology scouting activities, to identify potential threats and opportunities. To respond means that the corporate can invent, invest, incubate, acquire, or partner. A corporate that considers establishing a CIH in Silicon Valley, or any other innovation ecosystem in the world, need to develop an end-to-end corporate outpost strategy.

Research methodology

As the main author of this paper was heading up one of the CIHs included in this study the research methodology is influenced by action research. A combination of participatory observations and semi-structured interviews with other CIH leaders and team members was used to develop a deeper understanding of the different approaches, experiences, and lessons learnt. The interviews were followed up with a survey, where some responses triggered new questions leading to additional interviews.

To explore corporates' intentions, expectations and ways to manage and support their CIHs, six CIHs are included in this study. Interviews were performed with CIH leaders and team members, and a few individuals based at the corporate headquarter. The interviews were followed up with a survey and in a few cases followed up with further interviews. The studied companies share the following characteristics:

- large firms with headquarters far away from Silicon Valley; all but one large incumbents with decades of success as their legacy,
- the "mothership" is based in a country or region with a completely different culture,
- all operating in mature manufacturing industries
- established a CIH in Silicon Valley less than 6 years ago

Some differences between the studied CIHs were reporting level for the CIH head, size of the local team and the CIHs' level of autonomy. The mission given to the CIHs from their motherships differed as well, see Table 2 below.

Table 2 Corporate Innovation Hubs included in this study

Company	Reporting to	Local team size	Level of autonomy	Mission from mothership
A	CEO	<100	100%	Self-disruption, "future of industry"
B	CEO -3	<10	0%	Digital innovation in partnership
C	CEO	~200	70%	Be in s/w development forefront
D	CEO	<10	50%	Fast follower of competition
E	CEO -1	~100	70%	Make use of Silicon Valley presence
F	CEO -1	<10	100%	Technology scouting, finding startups

One common challenge for all CIHs was to make the mothership care to understand the Silicon Valley culture. To visualize all types of connections and interactions the local team at a CIH need to deal with the main author created below figure.

Figure 1 The main author's internal explanation of the three Silicon Valley domains

The intention with it was to visualize how "worlds are colliding" and how it is necessary to participate in all to be regarded as a serious, reliable and reputable local actor.

The figure shows three clustered domains, or "worlds"; the Tech companies world, the Startup world and the Research world. The Tech companies world include competitors, peers in similar industries, customers, suppliers – old, established tier 1 suppliers as well as new ones. It also includes original Silicon Valley firms: Oracle, Cisco, Intel, etc. and new ones: Amazon, Google, Apple, etc. This world also include bold disruptors, in many cases those that draw the incumbent's attention to Silicon Valley: Tesla, Uber, Waymo, AirBnB etc. and resembles traditional business environments, but due to the mix of old and new, and the regional culture with higher cadence as well as more inclination towards experimentation and explorative collaboration. There is a quite stable financial balance between the actors as none of them is desperately "fighting for survival" and nobody go out of business if a contract takes half a year longer than intended. Delays might cause that the interest is lost as the Silicon Valley innovation ecosystem is spinning fast, but that engagement can often be recovered later.

The Startup world includes the startups, their investors, talent pools, incubators, such as Y Combinator and 500 Startups, and accelerators, such as Plug & Play. The nature of this domain is different because startup companies here are pressured by investors to show progress. Speed and willingness to take calculated risk is what matters most and regardless if you are going to invest, become a customer, or partner with the startups, you need to move quickly to be considered serious. A traditional, risk-averse corporation with focus on exploiting existing businesses does not match the fast-moving, agile and opportunity-seeking mentality of the startup world, therefore a local CIH team can be a bridging mechanism since it operates similar to a small startup, as long as it is given the right level of freedom and autonomy.

The Research world includes universities, undergraduate and PhD students, senior researchers, faculty members at the universities, policymakers, city and state authorities, regional and federal agencies with funding or regulation responsibilities. This domain also includes port authorities, airport authorities, and cross-sector networks for regulation and policy topics. The reason for this is that the main author got connected to those through the academia network. This domain is stable, structured, highly interdependent and requires a long-term relationship with a high level of mutual trust. This world bridges into the other worlds through strong and loyal alumni networks, publicly funded collaboration projects and topic-focused, conversation-driven events. To be seen as a sincere Silicon Valley actor it is necessary to be an active part of this domain, partly because this shows that you have a vested interest in higher education and partly because it enables quick and low-cost proof of presence, through internship students, sponsorship of university education with problem statements, guest lectures and financial contributions, and of course participation in academic research. Several university collaborations generate broad, vital networks through events hosted on campuses and online, as well as the fact that students the CIH works with becoming professionals in local companies and stay connected. Beyond the direct value of being connected with Silicon Valley academia and benefit from their talent pool, their courses and their research, the open boundaries also make it crucial to be part of all domains – otherwise, there will be “glitches” in the attempt to establish a solid and trusted Silicon Valley presence for the corporation.

All interviewees in this study provided their personal experiences and perspectives on what works well and what is challenging in their particular CIH context. Literature reviews and insights from the interviews generated a list of desired conditions, which led to a follow-up survey with Silicon Valley based CIH employees only. The individual responses generated additional interviews for deeper understanding. The survey questions are listed below:

1. The CIH team is multi-disciplinary, with high-level of diversity and collaborative spirit, so-called T-shaped *(rate your CIH on a scale from 1 to 5)*

2. The CIH team uses an agile and iterative process allowing for reflection, rethinking and change of direction based on learning *(rate your CIH on a scale from 1 to 5)*

3. The CIH team include each other in daily work and utilizes diversity as a strength, all the way from insight building to proof-of-concept, instead of individual work, weekly progress reports and hand-offs *(rate your CIH on a scale from 1 to 5)*

4. The mothership provides purpose and direction, is transparent and inclusive. The CIH team understands how to pursue ideas and influence decisions *(rate your MS on a scale from 1 to 5)*

5. The mothership’s leadership is focused on competences, learning and progress in the CIH - rather than resources and budget *(rate your MS interaction on a scale from 1 to 5*)

6. The CIH team feel safe with each other, embraces disagreements and knows that they can speak their mind and get support, thanks to psychological safety (*rate your CIH on a scale from 1 to 5*)

7. The CIH team embrace failures as learning opportunities and openly share successes and failures in a non-judgmental way (*rate your CIH on a scale from 1 to 5*)

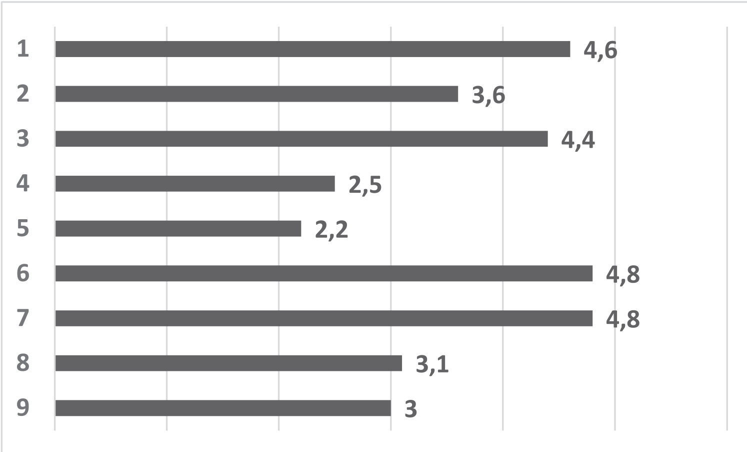
8. The interaction with the mothership is strongly influenced by external factors (such as market trends, customer needs and technology development), not internal budgets and governance *(rate the interactions on a scale from 1 to 5)*

9. The CIHs external collaboration with startups, tech giants and academia work well, and is utilized by the MS *(rate the CIH/MS external collaboration performance on a scale from 1 to 5*)

10. Does the CIH core team and/or leader have interactive conversations with C level executives regularly *(Yes or No*)

For survey question 10, the responses were divided with 70% of "Yes" answers and 30% of "No" answers. For survey question 1-9 responses, see table 3 below.

Table 3 The follow-up survey responses for question 1-9 (average of rating from 1 to 5)



4 Discussion

Table 3 presents the average rating in the responses and shows that there is room for improvement, particularly when it comes to the dynamics between the mothership and the CIHs. When analyzing the individual responses, mapping them against the differences between the CIHs, some patterns emerge. It turns out that the local CIH teams are all multidisciplinary, embraces diversity, has a high level of psychological safety and embraces failure as a learning experience without judgement. The following differences are observed:

- CIHs with high level of autonomy are applying more agile, iterative ways of working than the ones with a low level of autonomy and strong dependence of the corporate decision process.
- The higher the level of reporting, the clearer the intention and expectation from the mothership is. The CIHs with the highest reporting level also gave the highest rating on question number 5, regarding focus on competences, learning and progress rather than budget and resources.
- All CIHs with reporting level below CEO -1 rated their mothership interaction (question 4, 5, 8 and 9) lower than 3. High reporting level, high level of autonomy and regular interaction with C level executives lead to more externally oriented focus and actions.
- Answers to question 9 triggered further questions, and subsequent interviews showed that reasons for low ratings differed between the CIHs. Teams with high level of autonomy experiences good collaboration in the Silicon Valley ecosystem, but struggle to integrate the outcome from the collaboration into the mothership. For teams with a low level of autonomy, the struggle sometimes begins with the first non-disclosure agreement needing to be signed by someone at the mothership, sometimes due to waiting time, sometimes only because when the startup realizes that the head of the CIH does not even have authority to sign an NDA it indicates that this will not be a straightforward local collaboration with mutual trust, but will be dependent on an executive in another country and time zone, with less dynamic and collaborative culture, and with lower cadence. Then there is the internal politics within large corporates, with interdependencies between senior colleagues at the headquarter. The team at the CIH are considered as outsiders, rarely included in any of the internal politics, rather tolerated, or even ignored, maybe just forgotten.

To establish a Silicon Valley-based Corporate Innovation Hub is demanding, difficult, expensive, and sometimes quite frustrating work. One of the interviewees who is heading up a successful CIH for a large, mature incumbent said:

> "If you are looking for appreciation or recognition within your company - this is definitely not the job you want."

All CIH teams experience internal skepticism and pushback due to the cultural differences and corporate processes, procedures and policies. All CIH teams express strong commitment to their mission, loyalty towards their employer and high level of stress and frustration due to lack of understanding of – and interest for – Silicon Valley within the larger organization. It is likely that CIHs can be more successful if the presence in Silicon Valley is more proactively, consciously and systematically managed. The following focus areas are identified as priorities:

- Organizational intent: Why are we present in Silicon Valley?
- Outcome expectations: How do we define success?
- The local team: Who are the individuals for our winning team?
- The reporting level: On what level in the hierarchy do we need broad understanding of what is going on in Silicon Valley, and how to best support the CIH?
- The head of the CIH: How to find the individual that can be the bridge and the buffer?

Organizational intent: Why are we present in Silicon Valley?

With clarity about the intent with the CIH and direction, support and commitment matching with that intention it is possible for the CIH to build reputation and make early wins independently of the mothership's processes and procedures. With clear organizational intent, the local team can actively engage in the open boundaries ecosystem and establish the foundation for successful operation in Silicon Valley.

Several of the CIHs invite corporate executives to "demo days" in order to gain respect and appreciation for its work. These showcases are helping the CIHs to visualize their advanced technology knowledge and helps the executives to determine CIH focus and responsibilities. The intention with Silicon Valley presence is preferably both broad and flexible, in order to enable continuous knowledge building and external explorative collaborations.

Outcome expectations: How do we define success?

With autonomy to operate within a broadly defined organizational intent and clear budget frame, the CIH can respond well to clearly defined outcome expectations. This helps the team to focus on the right things and move with Silicon Valley cadence, establish partnerships and build reputation. The outcome expectations are important and need to be adjusted over time. One of the interviewees explained Silicon Valley presence in this way:

> "You can't come here and do cherry picking, either you are part of the Silicon Valley ecosystem wholeheartedly, or you are not."

While there is flexibility when it comes to effort and commitment, the CIH mission for achieving win-win for both the mothership and Silicon Valley must be clear. With clearly defined OKRs (objectives and key results) formulated with both a corporate and a regional perspective the CIH can operate effectively. Metrics that signals value for the corporate are for example related to collaboration with startups, academia related activities and tech giant partnerships. Metrics that signals value for the region are rather related to job opportunities, generated tax income, new local partnerships, new types of interactions, visitors, investors, services, facilities etc.

The local team: Who are the individuals for our winning team?

The local team constellation depends on the intention of the CIH. All the CIHs in this study value multi-disciplinary teams with "T-shaped" individuals (Patterson, 2017). The benefit of building the team with local talents, and utilizing their existing networks is recognized by many of the interviewees, while it is also seen as crucial to have team members that understand the corporation's culture and is well connected with the mothership.

The reporting level: On what level in the hierarchy do we need broad understanding of what is going on in Silicon Valley, and how to best support the CIH?

An appropriate hierarchical level in the organizational structure removes both confusion and frustration. Because of the open boundaries in Silicon Valley, it is necessary to provide the right level of support and autonomy to the local team in order to enable them to swiftly act on opportunities. Strong commitment from the mothership makes it easy and undramatic to involve the right internal experts without internal governance and delays. Such close connection increases the likelihood of success tremendously. Heads of CIHs that report directly to C-level executives and interact with the executive boards regularly express the lowest level of stress and frustration and feel more respected, appreciated and more empowered to do what matters the most. A CIH based HR executive initiated a "corporate intrapreneurship program" where employees develop competencies learnt from Silicon Valley to be able to self-disrupt the corporate, an initiative that would have been impossible with a lower level of reporting. The open boundaries in Silicon Valley lead to broad conversations and promising opportunities dynamically and with high speed.

The main author experienced going to a meetup event to learn about a startup with an active safety solution and ended up discussing electrification or automation of a transport system at an airport, with strong support from public funding and media attention prepared. Having a presence in Silicon Valley without authority and trust to participate in such conversations undermines the CIHs reputation and relationships. The local CIH team will not be able to get involved in everything, but need to feel empowered to take part in such conversations and channel them to appropriate colleagues rapidly, otherwise the highly connected Silicon Valley ecosystem realizes that the CIH is unable to participate effectively and will move focus to other more interesting actors in the region.

The head of the CIH: Choosing the individual that can be both the bridge and the buffer

This individual needs to fit into the Silicon Valley culture to attract talents and collaboration partners. At the same time, the person needs to understand the corporate culture and be able to interact effectively with internal interfaces when dealing with issues related to corporate policies, HR, finance, IT, R&D, legal, communications and management.

This individual need maturity, experience, drive and resilience to make the CIH function and add value to the corporate despite internal challenges. Lacking support and understanding from the mothership is common and caused by cultural clashes and human nature. This individual represents the corporate in front of external networks and the CIH team and is also representing the local team and Silicon Valley opportunities in front of the mothership. The head of the CIH connects and translates for two sides unable to understand each other and functions as a buffer between them in order to take advantage of the Silicon Valley presence.

The head of the CIH also needs to be a visionary and a storyteller. Attracting partners in the Silicon Valley ecosystem requires a bold, big vision. Attracting talents requires a big vision – and a challenge where they can see themselves be the heroes. The big CIH vision need to resonate well with the mothership to secure commitment and support. The head of the hub provides vision, direction, protection and inspiration to the local team – and of course compensation matching with the Silicon Valley culture.

5 Conclusions

All CIHs are experiencing challenges in the interaction with the mothership. The less autonomy and the further down in reporting level, the more difficult are the challenges, but with full autonomy and reporting to the CEO the value of the Silicon Valley presence is questionable. The difficulty for the CIH team to make their corporate counterparts understand and appreciate the Silicon Valley culture causes stress, inefficiency, and lost opportunities. Accepting the differences and embracing the Silicon Valley uniqueness as a competitive advantage is recommended.

The initial two research questions were utilized to search literature and to guide the semi-structured interviews:

Q1: Do the corporates that establish CIHs in Silicon Valley have clear intentions with and expectations on their CIHs?

Q2: How are the CIHs established, operated, managed and supported?

The answers to those research questions are:

A1: The CIHs in this study had different intentions from their motherships and also different levels of clarity and limitation. Some of the CIHs had both unclear intentions and intentions that changed over time. The expectations were in all cases unclear from the mothership and in the cases where the CIH team members themselves were allowed to define the expectations, the value of the CIH was considered higher.

A2: All the CIH leaders demonstrated an impressive balance between entrepreneurial mindset and commitment to their employers. Maybe this balance is formed by the role that requires it, or maybe this type of job attracts this type of people. The level of autonomy, reporting level, size of CIH team, and interaction with C-level executives was different, but the stories, stress triggers, frustrations, and wanted conditions for maximum value were similar.

The interviews generated the survey questions that enabled the study to find answers to the third question:

Q3: Can the insights from the different CIHs be utilized as information to increase the likelihood of a successful investment?

A3: Yes. These insights can help in setting up the best conditions considering intentions, expectations, autonomy, reporting level, and understanding of the Silicon Valley habitat, at the same time as it can prepare the corporate for the challenging interaction dynamics that all CIHs are experiencing. The buffer role can be formalized and appreciated as an important intermediary and given appropriate support.

One of the most challenging cultural clashes between a large mature firm and Silicon Valley is the difference in cadence. This alone can be enough for a CIH to fail, for example when trying to initiate an exploration-focused collaboration between Silicon Valley-based partners and not having the autonomy to do so independently. To be considered an attractive partner in Silicon Valley one must be able to move immediately. This does not mean that the CIH should have total freedom to operate, but at least the level of autonomy and trust for the mothership to get initial traction and prepare for scaling up the collaboration.

It is possible to increase the efficiency and the likelihood of success for a CIH by consciously and continuously provide the right conditions for the CIH team, starting from a thorough understanding of the Silicon Valley culture and how those cultural differences can be used as a competitive advantage for the corporate.

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Paper D

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Mitigating not-invented-here and not-sold-here problems: The role of corporate innovation hubs

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ABSTRACT

Despite a growing number of Corporate Innovation Hubs (CIHs) in recent years, limited attention has been paid to understanding the key problems that arise among organizations collaborating through CIHs. In particular, organizations often experience Not-Invented-Here (NIH) and Not-Sold-Here (NSH) problems, i.e. negative attitudes towards absorbing external knowledge and towards sharing internal knowledge externally. Consequently, many CIHs fail to deliver and are regarded as "innovation theatres" rather than engines of renewal. By drawing upon an inductive multiple case study of five CIHs, their parent companies and associated startups, located in Silicon Valley (USA) and the Gothenburg region (Sweden), the article sheds light on how CIHs can mitigate NIH and NSH problems in knowledge transfer. Specifically, we investigate the causes, consequences and mitigating mechanisms of NIH and NSH problems among the organizations collaborating through a CIH. These findings are presented in a framework that connects causes and consequences with the corresponding mitigating mechanisms. We also present new theoretical implications for the literatures on NIH and NSH.

1. Introduction

A Corporate Innovation Hub (CIH) mediates knowledge transactions and scouts for new ideas, concepts and technologies (Berger and Brem, 2016; Monteiro and Birkinshaw, 2017) by acting as an intermediate between incumbents and startups (Crisan et al., 2019). CIHs act as engines of renewal by creating bridges into innovative ecosystems where key organizations can collaborate to generate value by exchanging knowledge (Kupp et al., 2017; Walrave et al., 2018). For example, Honda established Honda Innovations where they have collaborated with over 40 startups and recently announced a partnership with SoundHound Inc., a leading innovator in voice-enabled AI (Fehrenbacher, 2019; Honda, 2018). The establishment of Honda Innovations enabled knowledge transfer among involved organizations in Silicon Valley to generate new business and innovative technologies (Ohnsman, 2017).

Knowledge transfer is defined as a process by which knowledge gained from one situation can be applied to another (Singley and Anderson, 1989). CIHs, typically established by large incumbent companies such as Honda, Ford, IBM, Walmart or Microsoft (Berger & Brem, 2016; Bhan Ahuja, 2019; Hausberg & Korreck, 2018), are vital for knowledge transfer (Kötting, 2019). CIHs both absorb and share knowledge (Aquilani et al., 2017) among their collaborating organizations as they mediate knowledge transactions (Kohler, 2016; Zahra, 2015). The absorption of knowledge happens when transferring knowledge from external organizations (such as startups) into an incumbent company, whereas sharing of knowledge occurs when transferring corporate internal knowledge to external organizations. The organizations involved thus explore new ideas and opportunities together, and exchange different types of knowledge (Schuh et al., 2017).

However, achieving collaboration and knowledge transfer through CIHs is far from easy. One of the challenges is that the organizations involved are fundamentally different in terms of company culture and management style (Van de Vrande, De Jong & De Rochemont, 2009; Weiblen and Chesbrough, 2015). Many CIHs also report problems with

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opportunistic behavior and a lack of peer support when bringing ideas from a CIH to the parent company (Fecher et al., 2020; Longo and Giaccone, 2017; Monteiro, 2015).

For these reasons, CIHs need to deal with two key challenges in knowledge transfer: the "Not-Invented-Here" (NIH) and "Not-Sold-Here" (NSH) problems (Antons et al., 2017; Chesbrough, 2003; De Araújo Burcharth et al., 2014; Berger and Brem, 2016). Chesbrough (2003) describes NIH and NSH as two viruses, which create an allergic reaction when transferring knowledge among organizations.

The NIH problem is a negative attitude to external knowledge (Katz and Allen, 1982), resulting in a rejection of external ideas (Hjalmarsson, Jordanius, Juell-Skielse, & Kailas, 2019). NIH is a major problem in inbound open innovation processes (Chesbrough, 2003; Cohen and Levinthal, 1990). As Antons and Piller (2015, p.197) point out, NIH results in *"… negatively shaped attitudes of an individual towards knowledge that has to cross a contextual disciplinary, spatial or organizational (functional) boundary, resulting in either suboptimal utilization or its rejection"*.

In contrast, NSH is a protective attitude toward external knowledge exploitation (e.g. via joint-venture relationships, licensing agreements, or free revealing) (Bianchi et al., 2011; De Araújo Burcharth et al., 2014). NSH hinges on the fear of losing competitive advantage when transferring a firm's internal knowledge assets to outsiders or sharing them with other organizations, and is regarded as a major problem in outbound open innovation processes (Chesbrough, 2011). NSH may result in mediocre solutions, terminated projects, or technology left sitting on the shelf (Grönlund et al., 2010). Arguably, both NIH and NSH hinder effective knowledge transfer among startups and parent companies collaborating through a CIH (Antons et al., 2017; De Araújo Burcharth et al., 2014). For example, Hannen et al. (2019) provide evidence from 565 global R&D projects that NIH is widely common and hinders the absorption of external knowledge. When one or both of these syndromes are present, organizations collaborating through a CIH will not be able to capitalize fully on their partnerships, and the CIH fails to achieve its mission.

We address two gaps in the extant literature on NIH and NSH. First, prior literature on NIH and NSH problems has a bias towards dyads, i.e. knowledge transfer between two companies or countries (Antons and Piller, 2015; Aquilani et al., 2017; De Araújo Burcharth et al., 2014; Hussinger and Wastyn, 2012; Kathoefer and Leker, 2012). Few prior studies thus consider the context of intermediaries such as CIHs to enable knowledge transfer among multiple organizations (Berger and Brem, 2016; Kohler, 2016) from an ecosystem perspective (Hannen et al., 2019), which is often the case in practice. For example, prior studies have mainly focused on knowledge transfer between a parent company and a CIH (Monteiro and Birkinshaw, 2017), thus excluding startups. And the limited number of studies that exist (e.g. Aquilani et al., 2017) conclude that both NIH and NSH problems arise in intermediates exploring ideas and transferring knowledge, but these studies are based solely on conceptual analyses of the literature. Second, most prior research focuses on either NIH or NSH, or proposes generic remedies for both problems. For example, Schuh et al. (2017) highlight the importance of understanding NIH in knowledge transfer through a CIH but do not consider the importance of and Aquilani et al. (2017) propose trust to mitigate both problems. In open and coupled innovation processes, which are characterized by active inward and outward technology transfer, both NIH and NSH should be considered (Frishammar et al., 2019) and appropriate mitigation mechanisms may be different for the two problems. Specifically, prior research has demonstrated that CIHs are often struggling in knowledge transfer (Fecher et al., 2020; Hannen et al., 2019), but the literature is still largely tacit regarding the specific hindering factors in relation to NIH and NSH problems.

For CIHs to successfully act as intermediates enabling knowledge transfer among their collaborating organizations, especially their parent company and startups, more research is needed to understand the specific hindering attitudes and their mitigating mechanisms (Del Sarto, Marullo & Di Minin, 2018; Fecher et al., 2020; Hannen et al., 2019). In addition, increased awareness of the consequences is a step towards better understanding NIH and NSH problems and their causes. This article, therefore, sets out to enhance the literature of NIH and NSH problems in knowledge transfer, from the perspective of a CIH (Del Sarto et al., 2018; Schuh et al., 2017; Zahra, 2015). The overall purpose of our study is to ascertain the following: *How can corporate innovation hubs mitigate not-invented-here and not-sold-here problems in knowledge transfer?* To operationalize this purpose, the following three research questions are addressed: *What are the causes of NIH & NSH problems among organizations collaborating through a CIH? What are the consequences of NIH & NSH problems among organizations collaborating through a CIH?* Finally, *What mechanisms can a CIH use to mitigate NIH & NSH problems among collaborating organizations?*

2. Theoretical background

2.1. CIHs and knowledge transfer

CIHs are typically situated in clusters of connected companies and institutions based on technological or economic concentrations (Porter, 1998). In these clusters, innovation ecosystems evolve, of which CIHs can form an integral part (Adner, 2017). Other key organizations are startups, incumbent corporations, investors, and academic institutions, all of which may collaborate when their interests align (Adner, 2017; Salomaa, 2018). In other words, a CIH is part of a structured micro-ecosystem where organizations seek to explore potential value propositions together by fostering the dynamics of innovation and entrepreneurship (Adner, 2017; Banc and Messeghem, 2020). However, not all CIHs are the same (Pauwels et al., 2016; Weiblen and Chesbrough, 2015), yet they share the mission of generating new ideas, concepts and technologies to bring to their parent company. Some CIHs are more focused on technology scouting and exploration, some engage in academic research, and still others focus on generating new business solutions together with partners. CIHs are thus, in some respects, similar to corporate incubators and accelerators. Incubators and accelerators are, however, broader and more all-encompassing phenomena. Accelerators can be considered to be a particular form of incubators; this is discussed in detail by e.g. Hallen et al. (2020) and Hausberg and Korreck (2018). CIHs differ from corporate accelerators, which often focus on scaling startups (Kanbach and Stubner, 2016; Monteiro and Birkinshaw, 2017). In this study we view CIHs as independent and boundary-spanning corporate units set up outside ordinary business structures which mediate knowledge transactions and whose mission is to scout for new ideas, concepts and technologies (Berger and Brem, 2016; Monteiro and Birkinshaw, 2017).

The purpose of a CIH is thus to explore new ideas, technologies and knowledge that can be used to generate new customer solutions or new business by performing an intermediation role (Euchner, 2016; Kohler, 2016). A CIH thus plays a key role in transferring knowledge among its parent company and associated startups, where the knowledge transferred can take different forms, such as domain-specific knowledge in the form of technical expertise, datasets, patents, etc., or procedural knowledge in the form of product development methodologies or guidelines (Schuh et al., 2017). CIHs are thus different from independent intermediaries in open innovation. Independent intermediaries are stand-alone entities seeking to mediate between organizations seeking external solutions for innovation-related problems and potential solution providers (Diener et al., 2020). By contrast, the key objective of a CIH is to supply the parent corporation with whatever knowledge is needed, but knowledge transfer is often two-way, in a reciprocal process. That is to say, parent corporations can also supply startups with critical knowledge through CIHs (Kohler, 2016).

2.2. Causes and consequences of NIH & NSH problems

On an overall level, Katz and Allen (1982) argued that the presence of NIH will generate incorrect evaluations of external ideas, leading to difficulties in seeing possible benefits and a decline in communication with external organizations. Prior literature on NIH and NSH problems among organizations collaborating through CIHs is limited, but an intermediate hypothesis is that CIHs and their collaborating organizations experience significant problems in knowledge transfer. For example, Chesbrough (2003) argues that NIH and NSH are counterpart syndromes, both hampering and undercutting the effectiveness of knowledge transfer among organizations when collaborating in an open innovation setting. The author further argues that NIH is more likely to be present in R&D projects; while NSH is more often found in projects centering on the business side.

Prior literature traces NIH problems to multiple causes. First, Antons and Piller (2015), in an extensive literature review of NIH, argue that NIH derives from psychological ownership, selective information processing, confirmation bias and disciplinary background. Psychological ownership occurs when specialists have a desire to defend their expert status, which can be at odds with new knowledge that is put into use. Selective information processing is an issue when managers experience difficulties in making evaluations when they and others involved approach a situation from different backgrounds and disciplines, and are thus led to contradictory conclusions. In contrast, confirmation biases are triggered by incentives and prior knowledge and understandings, e. g. when peoples' actions are directed towards the best outcome for themselves. Lastly, differences in individuals' disciplinary backgrounds may imply that startups and mature corporations within certain domains might be more affected by NIH than those in other domains. However, while the review by Antons and Piller (2015) provides important insights, it was not carried out in the context of CIHs. Second, Kathoefer and Leker (2012) propose that the likeliness of NIH depends more on personal traits than disciplinary background. This study was also, however, outside the context of CIHs. Third, Chesbrough (2006) argues that NIH is due to the fear of failure in selecting the right external ideas to work with. Fourth, Hussinger and Wastyn (2012) argue that NIH is more likely to occur when sourcing knowledge from competitors. Both these latter studies provide important insights into the NIH phenomenon, but also disregard the CIH context. For example, the ways that CIHs, startups and parent companies perceive each other's knowledge will greatly affect NIH problems, but arguably also its potential solutions. By taking an ecosystem perspective (Hannen et al., 2019), new insights into causes and consequences may follow (and by extension also new ideas for mitigating mechanisms). If these causes are not properly managed, NIH results in individuals underestimating the value of external knowledge and overestimating the efforts needed to absorb it, leading to either rejection of new knowledge or poorly performed implementations of such knowledge, and hence suboptimal decision-making (Antons and Piller, 2015).

In contrast, prior literature traces NSH problems to three causes. First, De Araújo Bianchi et al. (2011) argue that the protective attitudes at the core of NSH problems are driven by social influences embedded within a corporation's innovation culture, including norms, values and principles. As described by the authors, *"... employees feel that if the knowledge or technology cannot be exploited in own products or markets, it should not be exploited at all" (p. 151)*. Second, Aquilani et al. (2017) propose that the NSH problem may be linked back to a lack of openness, where companies face the dilemma of wanting to share knowledge externally but are stuck in old internal patterns of innovation. Likewise, Hoegl et al. (2011) argue that NSH attitudes may be strengthened by limited prior experience with outward technology transfer and the inefficiencies in markets for technological knowledge. Many companies may therefore have a stronger emphasis on exploiting internal knowledge. Third, Kline (2003) argues that NSH tendencies manifest through the fear of undermining a company's ability to retain fair value for its intellectual property rights or internal disagreements among employees about whether to license a technology or not. In a similar vein, Herzog (2011) argues that NSH tendencies can manifest through the fear of ending up in a legal dispute because employees are uncertain as to what knowledge they are allowed to share. It should be noted that none of these studies is in the context of CIHs, although Aquilani et al. (2017) theorize on intermediaries—theirs is, however, a purely conceptual paper.

If the causes of NSH problems are left unmanaged, negative NSH attitudes may result in fruitless knowledge exploitation, where startups and a parent corporation engage in collaboration without clearly showing their abilities, resulting in a situation where they are unable to make mutually beneficial exchanges. This situation might lead to frustration among employees at both startups and parent companies as their ideas, knowledge and technology are kept hidden and withheld from future development (Chesbrough, 2006). Arguably, this could lead to a feeling of distrust and disrespect (Kline 2003), resulting in demotivated employees who might even resign. As a result, companies with significant NSH tendencies often fail to profit from outbound open innovation (Hoegl et al. (2011).

2.3. Mitigating NIH & NSH problems in knowledge transfer through CIHs

Aquilani et al. (2017) argue that intermediates engaging in knowledge transfer among organizations, in a similar manner to a CIH, can mitigate NIH and NSH through a strong sense of trust and openness. This is further supported by Longo and Giaccone (2017), who argue that non-monetary awards and informal control mechanisms, while encouraging employees at CIHs to be proactive and committed towards common goals, mitigate conflicting personal interests. However, and specifically for NIH, Aquilani et al. (2017) argue that it can be managed by establishing new roles, such as an idea scout, idea connector, integration expert, technological gatekeeper or champion of innovation. The authors also propose that NIH problems can be eliminated altogether by choosing the right ideas and then fostering these ideas and providing appropriate contacts while integrating the ideas into internal R&D processes. In contrast, to manage NSH, companies need to identify the right partners to collaborate with, and be able to distinguish the sale of IP rights from startups or spin-off creations (Aquilani et al., 2017).

Summing up, research into the causes and consequences of NIH and NSH problems in a CIH context is scarce, and for potential remedies (i.e. mitigation mechanisms) it is even scarcer. Most of the existing so-called mitigating mechanisms are thought to mitigate both problems at the same time, without any deeper thought about each problem's specific root causes. The advice provided by prior literature is also quite generic. For example, Aquilani et al. (2017) argue that a strong sense of trust is needed by CIHs to mitigate NIH and NSH problems, but do not specify how to accomplish this. Second, both Aquilani et al. (2017) and Longo and Giaccone (2017)—the two studies that focus directly on CIHs—lack sufficient empirical data to confirm proposed ideas. In particular, there is almost no prior literature on NIH and NSH problems in knowledge transfer through CIHs among collaborating organizations. Given the state of prior literature, we opted for an inductive multiple case study to better understand NIH and NSH problems in a CIH context. The next section describes our methods for doing so in detail.

3. Method

3.1. Research strategy and case selection

Despite the research conducted over the past decades, the literature on NSH is still nascent. As prior research on knowledge transfer through

CIHs with multiple actors involved is also nascent, we adopted an inductive method (Gioia et al., 2013; Strauss and Corbin, 1998). The inductive approach allowed us to build theory and to let our understanding of the research area progressively emerge, as the use of initial exploratory interviews gave the empirical study its direction and provided the theoretical background with a starting-point. The Gioia method has emerged as the most popular one for inductive case analysis in leading journals (Del Sarto et al., 2018; Foege et al. 2019; Leone 2020; Mees-Buss et al., 2020; Sjödin et al. 2019). Recently published work also shows that this method is applicable to analyzing research questions which focus on answering "what" (Shankar and Clausen, 2020; Zhao et al., 2020).

To fulfill the purpose, multiple case studies of knowledge transfer among startups and parent companies collaborating through CIHs were conducted. Needless to say, a CIH is made up of individuals doing the work, so the individual is the main unit of observation. But their views have been aggregated to shed light on the CIH, since it is the CIHs that constitute the main unit of analysis.

We investigated five CIHs, each of which acts as an intermediate in sharing knowledge between parent companies and startups in its surrounding ecosystem. The cases were selected on three criteria. First, each CIH was operating in the automotive industry; an industry in rapid technological transformation under the ACES trends—autonomous driving, connected cars, electrified vehicles, and smart mobility. The automotive industry plays an important role in the global economy and for GDP growth (Saberi, 2018). Since 2010, investors have invested $220 billion into more than 1100 companies across ten technology clusters in this area (Holland-Letz et al., 2019). While the automotive industry overall is heterogenous, the parts of it to which the CIHs belong were homogenous. Second, each CIH engaged with startups and was owned by its corresponding parent company, which created a dependency of knowledge transfer among all the organizations in the ecosystem around the CIH. All CIHs were connected to a corporate venture capitalist (CVC) at the parent company to assure that promising new ideas, concepts or ventures could be financed. It should be noted that the number of CVC investments from Nordic corporates has more than doubled over the past five years (Oxford Research, 2019). Third, all CIHs actively explored novel transportation technologies through external collaborations, an area where NIH and NSH tendencies are high due to a tradition of developing technology in-house under a "closed innovation" logic (Rise Research Institutes of Sweden, 2018). For instance, CIH I is collaborating with startup Epsilon on automated driving systems at their location in Silicon Valley. This collaboration involves engineers from the parent company in Sweden, in an open innovation setting where NIH and NSH problems occur in this two-way reciprocal process of knowledge transfer.

All CIHs are briefly presented in Table 1. Since a few of the CIHs are hosted by larger R&D centers, the dedicated numbers of employees at each CIH unit is presented to facilitate comparability. It is important to point out that a larger CIH was able to execute more projects and activities than a smaller one, but the actual activities they performed were similar. All the CIHs studied are located in Silicon Valley, a global hub for high-tech innovation over the past 20 years (Cellan-Jones, 2020), but their parent companies are based in Sweden or Germany. The innovation ecosystem of the San Francisco Bay Area is one of the most venture capital heavy areas in the world. In 2018, 99.5 billion US dollars' worth of VC investments were made in the US, and 46% (45.6 billion US dollars) of those can be traced to Silicon Valley (PwC & CBInsights, 2019). At the same time, both Germany and Sweden score high on global innovation index rankings, where Sweden comes in second place after Switzerland (Cornell, 2019). Regarding the automotive industry, Gothenburg is a growing region receiving multiple international strategic projects and initiatives (Hermansson, n.d.).

Table 1
Key Information about the CIHs studied.

Corporate Innovation Hub	Description of Parent Company	CIH Location	Headquarter Location
CIH I Their objective is to leverage external innovation within digital technology through testing and developing new customer solutions together with organizations such as startups and tech corporations. Enable knowledge transfer in joint projects with the parent company. Established: autumn 2018. Number of employees at CIH: 5–10. Number of employees dedicated to CIH activities: 5–10.	Alfa European Automotive OEM, produces and distributes trucks, buses, construction equipment, as well as marine and industrial drive systems	United States	Sweden
CIH II Embrace new technologies, market trends and build capabilities within electrification and automation technology for future solutions. This is accomplished through collaborations with organizations such as startups, students and corporations, as well as connecting the parent company to joint projects. Established: autumn 2016. Number of employees at CIH: 100–200. Number of employees dedicated to CIH activities: 10–15.	Beta European Automotive OEM, produces and distributes cars	United States	Sweden
CIH III Sources world-class knowledge and talent for the future. This is accomplished by establishing collaborations with various organizations and by scouting for new technological advances. Established: 2018. Number of employees at CIH: 5–10. Number of employees dedicated to CIH activities: 5–10.	Gamma European Software company, develops and distributes software for driving systems	United States	Sweden
CIH IV Fosters innovation, collaboration and creativity within technology areas such as sensors, connectivity and automation. This is accomplished by interacting and collaborating with organizations such as startups, universities etc. Established: 1999. Number of employees at CIH: 200–250. Number of employees dedicated to CIH activities: 15–20.	Delta European supplier of automotive hardware and software, such as powertrain and injection technology, as well as steering and driving systems	United States	Germany
CIH V Delivers mobility solutions fit for the next generation. This is done by co-creation with startups within technology areas such as mobility and connectivity. The CIH has so far hosted 22 startups. Established: 2017. Number of employees at CIH: 3–5. Number of employees dedicated to CIH activities: 3–5.	Alfa, Beta and Gamma European CIH shared among multiple corporations to collectively engage with startups.	Sweden	Sweden

3.2. Data collection

Primary data was collected through semi-structured interviews in three waves over five months, from January to May of 2019. A total of 39 interviews were conducted, with 31 unique respondents. Of these, 14 were from CIHs, 12 from parent companies, 9 from startups, 2 from a research institute, 1 from a co-working space and 1 from a venture capital firm. The duration varied between 15 and 94 min—see Table 2 for an overview of the sample. Each interview was recorded and then transcribed. Interviews held in English were transcribed verbatim, whereas those held in Swedish were first transcribed in Swedish and then translated into English for analysis.

The *first wave* of interviews was intended to increase our understanding of the problems occurring in knowledge transfer processes through CIHs. Selected respondents provided valuable complementary information which enhanced our understanding of the most central organizations in such collaborations. For example, the venture capitalist interviewed had extensive knowledge from working with several CIHs. This first wave consisted of two sub-phases; one conducted in Gothenburg, Sweden, and the second in Silicon Valley, US, which spanned from late January to mid-March of 2019. The interviews used open-ended questions (such as “What challenges occur in these collaborations when transferring knowledge?“). A total of 9 interviews were held in Sweden and another 10 in the US.

The *second wave* of interviews was intended to seek more in-depth answers to the research questions, which had now been specified more fully. All respondents were chosen either based on previous interviews or recommendations from the first wave.

Respondents from startups were selected based on previous or ongoing collaborations with any of the CIHs being researched. Semi-structured interview questions were used, which enabled us to ask follow-up questions. These semi-structured questions were based on insights from the theoretical background as well as from the first wave of interviews. Questions such as “Why do you believe NIH/NSH problems occur in these projects?” and “How can such problems be mitigated by a CIH?” were asked. The interview questions were constantly edited and improved as wave two unfolded. In total, 18 interviews were recorded, transcribed and analyzed, and language differences were treated as in wave one. The second wave spanned the second half of March 2019.

The *third wave* of interviews was intended to confirm and consolidate the results, and to fill in remaining blank spaces. In this wave, we selected respondents that seemed to be the most representative of a CIH and its corresponding parent company. Two confirmative interviews were held, one at CIH I and one at parent company Alfa during May of 2019. Lastly, we relied on triangulation where data from the interviews and the emerging framework were discussed (Jick, 1979), i.e. to verify the different respondents’ viewpoints against each other. This was done through one workshop held in the US and two presentations with a subsequent discussion section which were held in the US and Sweden, respectively. The workshop was held with 6 respondents from both CIHs and Startups. The respondents were asked to react to, for example, how the causes, consequences, and mitigating mechanisms of NIH and NSH problems were labeled, and then were tasked with drawing connections among these. The workshop resulted in three alternative frameworks

Table 2
Overview of sample and respondents.

Respondent	Wave	Position	Organization	Country	Date	Duration	Type
R1	1	Project Manager	Research Institute Zeta	SWE	2019-01-29	51 Min	F2F
R2	1	Chief Technology Officer	Parent Company Alfa	SWE	2019-01-30	47 Min	F2F
R3	1	CEO/Co-Founder	Startup Theta	SWE	2019-01-30	16 Min	F2F
R4	1	Project Manager	Parent Company Alfa	SWE	2019-01-31	30 Min	F2F
R5	1	CEO/Founder	Startup Eta	SWE	2019-02-01	30 Min	VIDEO
R6	1	Director of CIH	CIH V	SWE	2019-02-04	40 Min	F2F
R7	1	Venture Capitalist	Parent Company Alfa	SWE	2019-02-05	41 Min	F2F
R8	1	Open Innovation Manager	Parent Company Alfa	SWE	2019-02-08	29 Min	F2F
R9	1	Project Manager	Research Institute Zeta	SWE	2019-02-12	46 Min	F2F
R10	1	Director of CIH	CIH I	US	2019-02-19	50 Min	F2F
R11	1	Director of CIH	CIH II	US	2019-02-19	77 Min	F2F
R12	1	Business Developer	CIH II	US	2019-02-21	59 Min	F2F
R13	1	Business Developer	CIH II	US	2019-02-22	63 Min	F2F
R14	1	Head of Sales and Strategy	Startup Omega	US	2019-02-27	24 Min	F2F
R16	1	Director of CIH	CIH III	US	2019-02-28	62 Min	F2F
R17	1	Innovation Advisor	Co-working Space Kappa	US	2019-03-01	45 Min	F2F
R18	1	CEO/Founder	Startup Sigma	US	2019-03-04	94 Min	F2F
R19	1	Senior Innovation Manager	Parent Company Alfa	US	2019-03-12	51 Min	F2F
R20	1	CVC Adviser	Venture Capital Psi	US	2019-03-13	45 Min	F2F
R21	2	CEO/Founder	Startup Epsilon	US	2019-03-14	40 Min	F2F
R2	2	Chief Technology Officer	Parent Company Alfa	SWE	2019-03-15	65 Min	VIDEO
R22	2	Venture Capitalist	CIH IV	US	2019-03-15	65 Min	F2F
R23	2	Venture Capitalist	CIH I	US	2019-03-18	44 Min	F2F
R24	2	Tech Scout	CIH IV	US	2019-03-19	59 Min	F2F
R7	2	Venture Capitalist	Parent Company Alfa	SWE	2019-03-20	68 Min	VIDEO
R10	2	Director of CIH	CIH I	US	2019-03-20	62 Min	F2F
R25	2	Business Developer	Parent Company Beta	SWE	2019-03-21	47 Min	VIDEO
R26	2	Chief Technology Officer	Parent Company Gamma	SWE	2019-03-21	40 Min	VIDEO
R12	2	Business Developer	CIH II	US	2019-03-21	44 Min	F2F
R5	2	CEO/Founder	Startup Eta	SWE	2019-03-22	48 Min	VIDEO
R27	2	Specialist	Parent Company Alfa	SWE	2019-03-22	55 Min	F2F
R28	2	Software Developer	CIH II	US	2019-03-22	35 Min	F2F
R14	2	Head of Sales & Strategy	Startup Omega	US	2019-03-22	55 Min	F2F
R29	2	CEO/Co-Founder	Startup Iota	US	2019-03-26	27 Min	VIDEO
R30	2	CEO/Co-Founder	Startup Pi	US	2019-03-26	68 Min	F2F
R31	2	Legal Advisor	Parent Company Alfa	SWE	2019-03-28	44 Min	VIDEO
R16	2	Director of CIH	CIH III	US	2019-03-29	41 Min	F2F
R10	3	Director of CIH	CIH I	US	2019-05-06	44 Min	F2F
R2	3	Chief Technology Officer	Parent Company Alfa	SWE	2019-05-13	31 Min	VIDEO

which guided the inductive theory development in subsequent steps.

3.3. Data analysis

We used the Gioia analysis, which is a structured yet flexible approach to analyzing qualitative data (Gioia et al., 2013). Our data analysis was carried out in three steps:

Step 1. Develop first-order categories and tentative second-order themes

The formal analysis began as we immersed ourselves in the data by reading it repeatedly and independently, in order to get an understanding of its depth and width. To ensure that there was a logical link between the interview questions and first-order statements, we paid extra attention to the initial interview protocol and the research questions. The first reading was made without taking notes, to ensure that patterns were only shaped after taking all the data into account. After the first reading, the analysis continued with open coding, in which statements related to each research question were highlighted. All statements were collected and first sorted on their relevance to each research question, and then sorted on their connection to either NIH or NSH. The procedure of axial coding followed, where related codes were connected to broader yet preliminary second-order themes. For example, statements coded as "*fear of losing control of technology development*", "*only accept technology according to established standards*", "*only consider knowledge from a trusted colleague*" and "*excessive guidelines to avoid unwarranted IP*" were categorized as "*Obsessive control*" whereas statements about "*anxiety of not living up to expectations*", "*procedural knowledge is not seen as competitive*" and "*domain-specific knowledge is seen as the main asset*" were categorized as "*Depreciation of knowledge*". To ensure that we adhered transparently and faithfully to informant terms, we made little attempt to refine the first order codes. This resulted in a rather large set of first-order codes and tentative second-order themes of causes, consequences and mitigating mechanisms.

Step 2. Iterate between coding scheme, data and the literature

The second step started with an iteration of the first-order codes and tentative second-order themes, to further refine and improve accuracy. In this step, we tried to figure out the larger narrative of the collected data—answering the important question "What's going on here?'' by narrowing down the link between first-order codes and second-order themes. This step included extensive discussions regarding the relevance of the second-order themes, revisiting the data and reviewing the literature for further refinement. When refining the second-order themes, we paid attention to their reflection of the first-order codes. For instance, first-order codes related to an individual's difficulty in understanding confidential knowledge were first organized under a second-order theme labeled *"Protection of unique knowledge"*. This, however, was later relabeled to capture the essence of the root-cause, resulting in the theme *"Confidentiality unawareness",* i.e. capturing the difficulty in distinguishing between confidential and public knowledge. This step further involved a revision of the first-order codes to ensure that they formed a coherent pattern from more than one respondent.

Step 3. Generate aggregated theoretical dimensions

In the third step, we created aggregated theoretical dimensions to delineate how the second-order themes were related. This implied a continuous iteration by referring back to the dataset to check whether they were suitable or if any of the first-order codes, second-order themes or aggregated theoretical dimensions needed further clarifications and/or amendments. The evaluation of possible models demonstrated that the causes of NIH problems were best illustrated by a map through the aggregated dimension of *Desire for excellence,* and NSH problems by *Fear of giving without receiving.* The consequences of NIH problems were best illustrated by a map through the aggregated dimension of *Resource inefficiency,* and NSH problems by *Painting oneself into a corner.* The mitigating mechanisms of NIH problems were best illustrated by a map through the dimension of *Alignment of objectives,* and mitigating mechanisms of NSH problems by *Creation of a knowledge sharing environment.* The last step consisted of analyzing the second-order themes in relation to the purpose of the study in a framework, connecting causes and consequences with the mitigating mechanisms.

As a last step, we went back to evaluate all the data and merge our results into a conceptual framework, thus strengthening the contributions of the inductive study by generating testable propositions (Gioia et al., 2013). The connections in the framework emerged as a result of analyzing how causes, consequences and mechanisms were associated and mentioned in the data, while the strength of a connection was defined by the frequency with which an association was repeated in the data. All this work resulted in an initial framework. This initial framework was then tested in a workshop in which six interview respondents from three different CIHs were assigned to draw connections and their prevalence among the causes, consequences and mechanisms, without knowing about the initial framework. The respondents arrived at similar connections with minor differences, such as to the connections between the mitigating mechanisms of NIH problems and their causes and consequences. Half of the respondents only perceived the mitigating mechanism *"translate relevance of ideas"* as having a strong effect on the consequence of lagging behind the knowledge frontier, whereas the others also perceived it as having a strong effect on the suffocation of external ideas. In addition, the ones who perceived it as having a strong effect on the suffocation of external ideas also drew lines to both of the mitigating mechanisms for NSH problems, arguing that both are needed in order to mitigate the causes of NSH problems. The outcomes of this exercise were later taken into consideration before finalizing our framework.

4. Results and analysis

This section presents the findings from the inductive analysis; see Fig. 1 for the data structure. Fig. 1 shows six dimensions representing the causes, consequences and mitigating mechanisms of the NIH and NSH problems that arise when collaborating through a CIH. Tables 3–5 provide representative quotations to support Fig. 1.

4.1. Causes of NIH & NSH problems arising when collaborating through CIHs

4.1.1. Causes of NIH problems

4.1.1.1. Desire for excellence. This aggregate dimension highlights the drive within the studied organizations collaborating through a CIH to be at the front of the race. When collaborating through a CIH, startups argued arrogantly that their main asset is their knowledge, and at the same time, parent companies were sometimes equally arrogant, stating that the superiority of their knowledge could not be questioned. Three second-order themes were identified for the causes of NIH: *Exaggerated knowledge valuation, Obsessive control* and *Internal antagonism.*

Exaggerated knowledge valuation. This second-order theme focuses on the generous self-evaluation of knowledge assets among organizations, especially concerning domain-specific technical knowledge. All respondents perceived others' knowledge to be of less value than their own and they also expressed difficulties in absorbing knowledge that was similar to their own. As the CEO and Co-founder of startup Iota (R29) stated:

> "I don't think that we learned anything from the domain expertise when collaborating through the CIH, we still have the upper hand when it comes to that."

Furthermore, all respondents expressed a fear of not being needed and of not being able to contribute to their organizations. This fear

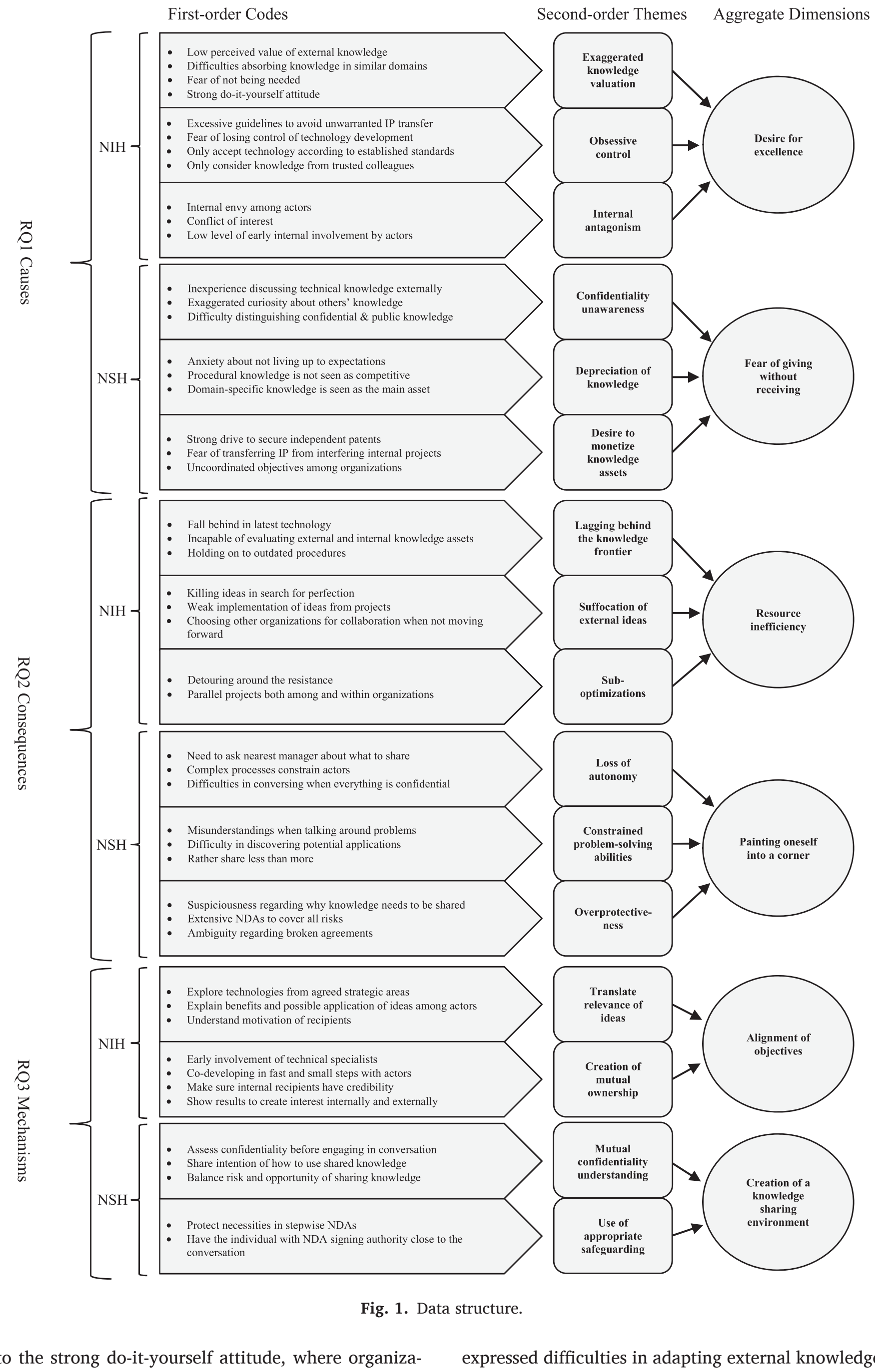

Fig. 1. Data structure.

might be linked to the strong do-it-yourself attitude, where organizations become defensive when external organizations question and challenge their knowledge, creating NIH problems among organizations when collaborating through a CIH.

Obsessive control. This second-order theme centers on the fear of losing control of one's technology development, where organizations expressed difficulties in adapting external knowledge due to the fear of becoming too strongly influenced by others and dependent on them. Respondents said that parent companies only accepted technology according to established standards, whereby external technology must be controlled to ensure it fits within their rigorous specifications. Moreover, knowledge is only perceived to be worth absorbing if it comes from

Table 3
Representative supportive data for RQ1, causes of NIH & NSH problems.

Dimension & themes	Representative quotes (CIH: Corporate Innovation Hub, ST: Startup, PC: Parent Company)
CAUSES OF NIH	
Desire for excellence	
Exaggerated knowledge valuation	"How hard can it be is what they say? How hard can it be? They've only put five years of effort into this startup so far. And what they don't count is the domain expertise you brought to it." (R14, ST) "There are engineers undermining the difficulties, you meet a startup that's been in existence for 10 years that solved a technical problem and then the engineers say, how hard can it be? In our parent company, we have many engineers, we must be able to solve this too." (R10, CIH) "Often, there's a bit of a disconnect, let's say, a brilliant smart guy in machine learning from a startup and then you have an electrical engineer, mechanical engineer, let's say at a known OEM. They can talk past each other. Not because they're bad people or intentionally trying to trick each other but because they just approach the world in different ways. I've seen many smart startup engineer's technologists that would say: That's silly, that's so completely the wrong way to think about it, we're just going to replace all that and it's going to be solved in this way." (R30, ST)
Obsessive control	"The second one is losing control of your technology yeah and losing sight of what your vision is as a company, and the third one is losing your competitive edge and being unneeded in industry." (R29, ST) "We realized quite quickly that we will not trust 100% of what the startup says, we will have to follow up that they have done solid safety checks." (R27, PC)
Internal antagonism	"Then you feel some envy, why are they in Silicon Valley allowed to sit there and come up with a lot of cool stuff? I'm only allowed to stare at quality problems." (R10, CIH) "Was extremely difficult to get it through, because they at the parent company weren't taking part in the concept development, they lacked context and could not understand the specific design choices we made and therefore didn't buy it." (R12, CIH)
CAUSES OF NSH	
Fear of giving without receiving	
Confidentiality unawareness	"Of my knowledge I might have 25% that I can share and 25% that I know that I cannot share. 50% is quite unknown and in most of the cases within this part, I turn to my supervisor to find out if it's allowed to be shared or not." (R27, PC) "Right so there's a bit of a give and take but you often get into situations where there is no give they just constantly want more, more, and more. You sit there like you're being interrogated right, I'm exaggerating a little bit, but I think that's the biggest concern, it's the fundamental IP and protecting the IP." (R30, ST)
Depreciation of knowledge	"If startups see what data we have collected from our vehicles and they realize they it can be replicated through a simple cell phone, then it becomes quite tough for us. So, what's the fear? It's that they might realize that all we have might not be that valuable as we believe." (R23, CIH) "I believe that domain-specific knowledge is more sensitive, it's what's building the value and the uniqueness of a company, rather than the process of how it is performed, e.g. a development project or a POC, or a manufacturing process, the uniqueness of a company is broken down into domain knowledge." (R5, ST)
Desire to monetize knowledge assets	"It's actually a huge challenge to find data. We can share data with startups to do a POC, proof of concept. But that's where you'd get into GDPR regulations and start to question who really owns the data? Is it ours since it was collected by us? But if it's collected by us and another company, then it's a tug-of-war on who owns the data, how we can utilize that and do what. I think that's kind of it's one of the things where it's really slowing some things down. So right now, we actually have a project of just trying to produce some data for POC's only." (R16, CIH) "We have our own technology project in this domain and we had even before the startup was established so we wanted to keep our own technology development within the parent company quite separately from collaboration … because we wanted to minimize the risk of that IP from us would slip into them." (R27, PC)

someone you trust, preferably your nearest colleague at the company. As a Tech Scout at CIH IV (R24) explained:

> "So, when we do corporate research, we would never advertise it until it is kind of perfect, especially in automotive we have a lot of guidelines and it has to fulfill some specific features."

Internal antagonism. This second-order theme centers on the perceived conflict of interest internally among parent companies and CIHs. The CIH and their parent company express internal envy towards each other due to limited understanding of each other's work, where both sides behave arrogantly, perceiving themselves as more valuable than the other. This envy frequently leads to a lack of motivation among individuals in organizations to onboard knowledge from each other and also to organizations starting to question what they will gain from it. As a Business Developer at parent company Beta (R25) said:

> "They have to start to communicate and not be the secret army that's simply sitting in Silicon Valley and does their stuff and believes they can do it so much better."

Besides, the parent companies rarely managed to become involved with the CIH-led collaborations at an early stage, and this led to a lack of understanding and limited contextual insight into the CIH. It is therefore difficult for them to accept new knowledge from the CIH.

4.1.2. Causes of NSH problems

4.1.2.1. Fear of giving without receiving. When collaborating through a CIH, organizations are constantly engaging in a process of reciprocal knowledge trading, so this dimension centers on each organization's desire to profit from the most valuable knowledge assets, while less desirable knowledge is overlooked. This dimension has three themes: *Confidentiality unawareness, Depreciation of knowledge* and *Desire to monetize knowledge assets.*

Confidentiality unawareness. This second-order theme demonstrates the low awareness of what is confidential as opposed to public knowledge that is shown by individuals in organizations collaborating through a CIH. When they are not clear as to what is confidential, individuals tend to ask inappropriate questions about others' knowledge. It often seems as though individuals in organizations are inexperienced in discussing advanced technologies externally, and are largely unaware that research has often become public knowledge. This creates unnecessarily anxious and restrictive behavior in discussions. A Venture Capitalist at CIH IV (R22) expressed awareness of confidentiality in the following way:

> "Experts who are working at the CIH, when they talk to an external party for the first time they are really afraid of talking to them and sharing anything, because if you are not used to it, you just don't know, you think everything is confidential, but it is actually not."

This implies that knowledge will most likely not be shared by employees of companies whose legal representatives state it is up to each individual to assess confidentiality but individuals claim that, on the contrary, it is the legal entities' responsibility.

Depreciation of knowledge. This second-order theme highlights each organization's insecurity about valuing knowledge, especially procedural knowledge, where individuals in organizations express

Table 4
Representative supportive data for RQ2, consequences of NIH & NSH problems.

Dimensions & Themes	Representative quotes (CIH: Corporate Innovation Hub, ST: Startup, PC: Parent Company)
CONSEQUENCES OF NIH	
Resource inefficiency	
Lagging behind the knowledge frontier	"Their reaction is that this is not at all a good idea, what we do here at the parent company is much better … And it is not so easy to compare this, because there is not a scale for comparing how good something is." (R26, PC)
	"My guess is that you can't use the same working methods anymore, so sometimes I wonder if the parent company's people are stuck in their procedural knowledge, and that it prevents them from developing anything." (R23, CIH)
Suffocation of external ideas	"You acquire the technology and the people, but you don't implement it properly and the whole thing dies and then you are there with people you don't need anymore, or they are unhappy because they see their ideas going down the drain and they are not producing anymore because they are unmotivated, and you waste money for nothing." (R22, CIH)
	"We get stuck in multiple processes, but we just want to discuss and solve the client company's problem, we want to be able to sell and don't want to be treated as if we were on some sort of speed-dating. We want to sell, we are a company and we run a business and just because we're a startup we don't want to be a part of someone's innovation statistics" (R5, ST)
Sub-optimizations	"We're not replacing what you do, you're not supposed to stop what you're doing at the parent company, but just in case this doesn't work out, let's have a separate project that is parallel to this." (R30, ST)
	"We had been able to bring in people from the parent company who have worked within this field for a very long time, where the startup had kind of zero knowledge. So, I think we could have cut huge amount of time if we had brought our resources to the project." (R27, PC)
CONSEQUENCES OF NSH	
Painting oneself into a corner	
Loss of autonomy	"Lots of times in this technology project I did not make the decision myself to share or not share, I asked my supervisor." (R27, PC)
	"I believe there is a risk of closing the relationship if you say that we will talk only about this, only this is confidential, then you might create an even greater fear of having a free discussion in these projects." (R31, PC)
Constrained problem-Solving abilities	"It turns into a catch 22 because you want to know what they can help us with, but we cannot tell them that. It's definitely a problem and it was difficult to understand how you were supposed to cope with it." (R12, CIH)
	"And so that's the hardest thing for us to have the time to know about other large companies like company is where does company want to be in 10 years? It allows us to make sure that problems that we're working on are the big issues to big companies and that we can be part of a solution to help that and we might be able to accelerate the that solution." (R14, ST)
Over-protectiveness	"If you forget to empty the dishwasher once, I will ask for a divorce, and I believe that's the big why people don't share knowledge since there's a huge ambiguity in the relationship." (R10, CIH)
	"And then two months later, when it comes to contract, she pulls out this contract or hands you to a legal person and the contract basically says you're selling your company to us for this project. The trust is broken." (R30, ST)

anxiousness about not living up to the other organization's expectations. Procedural knowledge is most often overlooked, since it is not considered as competitive in comparison to domain-specific technical knowledge. As a result, it is either shared without anyone noticing or considering its importance, or not at all. As the Chief Technology Officer at parent company Alfa (R2) said:

> "There's no one in the world that wants to share processes, no one wants to listen to it either. You will never be able to outrun anyone by copying someone else's working methods."

Desire to monetize knowledge assets. This second-order theme demonstrates each organization's fear of not being credited for their knowledge. Knowledge that can be translated into monetary terms is tightly protected to ensure maximum value in return. The tug-of-war regarding IP among organizations collaborating through CIHs is sensitive. For instance, parent companies keep their specialists in certain areas away from projects that are operating through the CIH in their domain, to minimize IP being leaked to startups. At the same time, startups say that IP-related knowledge is their only asset, and that it will not be shared until they are confident it will stay with them. The CEO and co-founder of startup Pi (R30) said:

> "At the end of the day, the reason why a small tech company can grow and continue to attract capital and relationships and do business is only because of specific, unique knowledge … So the only way to monetize that or to prepare is to protect that."

Additionally, in most cases, both organizations were afraid of ending up in legal disputes over exactly what knowledge each individual in each respective organization possessed before the project.

4.2. Consequences of NIH & NSH problems arising from collaboration through CIHs

4.2.1. Consequences of NIH problems

4.2.1.1. Resource inefficiency. This dimension centers on the ineffective use of resources when collaborating through a CIH, because it is difficult for individuals in organizations to remain updated when discussions and decisions are delayed and drag on due to high NIH tendencies. Three second-order themes were identified for the consequences of NIH: *Lagging behind the knowledge frontier, Suffocation of external ideas* and *Sub-optimization.*

Lagging behind the knowledge frontier. The first second-order theme highlights that NIH problems generate difficulties in assessing external knowledge and keeping up with the latest technology, since organizations are ignorant of existing knowledge gaps. The strong belief in own knowledge hinders the search for new technologies and makes it near-impossible to evaluate internal and external knowledge assets when collaborating through a CIH. As expressed by the CEO and co-founder of startup Pi (R30):

> "Over the long term, it can hollow out the company, when work continues to go on without anyone realizing the company is slowly falling behind the latest technology."

Suffocation of external ideas. In the search for perfection, CIHs are torn between startups and the parent company when trying to keep ongoing collaborations alive. When these collaborations terminate, this will most often be due to lengthy processes and demanding standards. Resources invested, for example in the development aimed at obtaining

Table 5
Representative supportive data for RQ3, mitigating mechanisms of NIH & NSH problems.

Dimension & themes	Representative quotes (CIH: Corporate Innovation Hub, ST: Startup, PC: Parent Company)
MECHANISMS TO MITIGATE NIH	
Alignment of objectives	
Translate relevance of ideas	"I think what matters is having the connection and ability to go to Sweden and to figure out how we at the CIH fits into the mission of the parent company as a whole. Once the CIH and the parent company understand each other's situation people at the parent company might think differently, the barrier of the not invented here starts to drop. Maybe the idea didn't originate from the parent company, but the CIH don't have the resources to do it, but the parent company does, and they can help the CIH. On the flip side of that, a startup that comes with an idea to the CIH, they have to be willing to let that go of it to some extent, like we have to be willing to let it go of ideas to the parent company" (R28, CIH) "Basically, proceed from a pointed-out technology stack where we have already realized that we need to partner up with others, and if something lies within that stack it would be easier." (R27, PC)
Creation of mutual ownership	"They must have expertise in place at the CIH, because otherwise the things that are getting done will not be relevant, we just did a POC within AI with a startup where we sent a specialist for two weeks, and they worked from morning to evening, together with the startup and then went home, it was successful." (R26, PC) "The CIH have to involve right people from the beginning, the faster you do that the faster people become receptive, people always seem to be more reluctant when handed a project too late in the process. You need to get people at the parent company to feel co-ownership and that their ideas are put into a context, then it is really difficult for them to say, no, we don't want to do this, they have to feel co-ownership early." (R5, ST) "Go out and present what the CIH are doing, how they work, ask if they want to be involved, show the benefits. You have to do this over and over, now I feel that it starts to go where we want." (R25, PC)
MECHANISMS TO MITIGATE NSH	
Creation of a knowledge sharing environment	
Mutual confidentiality understanding	"Persons has to go through some form of car-wash on the road to the CIH, we have to make sure that the culture here is cared for, that it is open-minded and forward-leaning. If you fly in someone we have to tell them that all NDA's are signed, all internal patents are managed, the startup's patents are managed, during this period you are colleagues, your job is to ensure that this POC succeeds." (R10, CIH) "Just being completely honest and upfront with the parent company, helps a lot to like, this is exactly what I intend to use it for. For this reason and if you're okay with that then I hope that you'll send that in and if that person is not okay with it then let's have a discussion as to why you're not okay with it." (R28, CIH) "Early on we came up with an interface project, an early interface project very clearly defines the role of each partner and the defining what knowledge is needed to be shared among each actor needed for that role so it, this party is developing the engine controller and that's it, therefore the knowledge share needs to be enough for them to share to come up with that." (R21, ST)
Use of appropriate safeguarding	"Have special contracts in place for startups. It was quick decision making, they weren't trying to get everything, all the IP and things like that. It's was very flexible and reasonable for what we're trying to do." (R30, ST) "Instead of it being so very formal when signing an agreement, it should be seen as a natural part of a work … when you step into the CIH you write a confidentiality agreement, on a digital tablet, with a preface form, that people should be able to sign in 2 min, just tick a box and when you start to develop something, you write a collaboration agreement that is fairly standard." (R31, PC) "Coming from a previous organization, the data was made available to any group and it didn't really matter whether you were doing engine design or engine development, whether you're doing electrical control systems for the engine, just everyone had access. Even the engine builders had access to it. I think that because of this expectancy of data availability, being in a data enriched environment help people make better decisions." (R28, CIH)

a patent, or in ongoing partner relationships, will be wasted when startups are acquired by others or when they choose to collaborate with other organizations. This has negative implications for the reputation of the CIH and its associated parent company. As a Venture Capitalist at parent company Alfa (R7) stated:

> "This resulted in a situation where we became restrictive and suddenly leaned towards the parent company and told the startup to continue the collaboration on their own, and every time they presented a new solution, much time was spent on finding errors and telling them to come back when it is perfect."

Sub-optimizations. This second-order theme highlights the consequences of the actions that are taken today towards solving NIH problems among organizations. According to startups and CIHs, you have to find ways to override the resistance in the parent company by, for example, going up hierarchies to receive knowledge or expert advice. As the Director of CIH III (R16) explained:

> "You basically have to find ways around that person at the parent company. With some people you just cannot win."

This will further affect implementations when people who are supposed to be involved within specific projects through the CIH are bypassed, creating even more resistance. In addition, sub-optimizations occur, such as when there are parallel projects, i.e. overlapping projects among organizations that run separately instead of being aligned.

4.2.2. Consequences of NSH problems

4.2.2.1. Painting oneself into a corner. This dimension emphasizes the fact that, when collaborating organizations cannot solve the problem they set up, they then become restrictive, resulting in a situation in which they do not know enough about the other party's knowledge. Three second-order themes were identified for the consequences of NSH: *Loss of autonomy, Constrained problem-solving abilities* and *Over-protectiveness.*

Loss of autonomy. Due to the low level of awareness among individuals in organizations as to what is confidential knowledge, employees frequently ask their immediate manager about what they are allowed to share. However, if the manager does not have the answer, organizations collaborating through a CIH will become constrained as to how to move forward in projects on their own. This consequence might be particularly problematic for CIHs connected to parent companies in other time-zones, since it increases the likelihood of delaying dialogues. A Senior Software Developer at CIH II (R28) describes it in the following way:

> "We have to adapt our schedules in order to help the relationship to grow with the parent company and develop it into a point where people over there feel comfortable actually providing us with knowledge that we need in order to get something done."

Constrained problem-solving abilities. When organizations that collaborate through a CIH share less rather than more, and talk around problems instead of talking directly about them, it will lead to misunderstandings and negatively affect the quality of work. Likewise, when employees at different hierarchical levels engage in discussions, they will most likely talk past each other. These misunderstandings will not only hinder the discovery of potential applications for new ideas but also increase the difficulty of assessing how well a solution fits into another company's product portfolio, making it almost impossible, as expressed by a Tech Scout at CIH IV (R24):

> "You always have to kind of talk around things, you cannot be specific, if you could be specific you could say okey we are doing this and that and we want to have that it would make things sometimes a bit easier."

Over-protectiveness. To ensure a company will be able to monetize its own knowledge assets, extensive protection and NDAs are often used. Organizations face a wall of suspicious employees, and this makes it difficult to progress the collaborations through a CIH. A Senior Software Developer at CIH II (R28) describes a situation when trying to get knowledge from the parent company:

> "You've seen as an outsider when working at the CIH and you've kind of shaking things up and asking questions that make people at the parent company feel uncomfortable. It's like, I need access to some data to do something. And it's like, why do you need access? It's like, Well, why do I even have to ask for access? It should be readily available."

4.3. Mechanisms mitigating NIH & NSH problems through CIHs

4.3.1. Mechanisms mitigating NIH problems

4.3.1.1. Alignment of objectives. This dimension emphasizes aligning objectives among organizations engaging in collaborations through a CIH in order to get them all on the same page when transferring knowledge. Two second-order themes were identified as mitigating mechanisms of NIH problems: *Translate relevance of ideas* and *Creation of mutual ownership.*

Translate relevance of ideas. To mitigate NIH, it will be important for the CIH to understand their position vis-a-vis the parent company. This will provide employees at the CIH with the confidence to understand what they can do in these collaborations as well as the ability to explain the benefits of ideas from multiple perspectives. As a Venture Capitalist at CIH IV (R22) highlighted:

> "Sometimes it's explaining the idea once more from our perspective, to explain that, no this is not what you tried, this is something else because of bla, bla, bla. Or talking to our people at the parent company and to figure out their motivations, I mean to some extent, because this takes time and we are not paid for that, but to figure out why the people are so reluctant."

For instance, ideas and new technology explored through CIHs would benefit, some respondents indicated, from being a part of a pre-agreed technology area of the parent company, aligned with the long-term strategy and supported by top management. These technology areas have to be communicated throughout the parent company, where we also believe it is important that the CIHs are clear to startups about which areas the parent company will pursue with external organizations through the CIH and which areas will be developed solely in-house. However, by CIHs translating the relevancy of ideas among organizations, NIH can be mitigated, since decisions will be mutually agreed, which makes knowledge transfer possible.

Creation of mutual ownership. Ownership agreements about projects, data-sets, technology advances, possible outcomes that might lead to patents—all these need to be established among organizations collaborating through a CIH. These agreements will mitigate the tendency to NIH that can be encountered when technical specialists are involved early on in tech-scouting activities. A Chief Technology Officer at parent company Gamma (R26) explained the benefits of involving recipients early on, but also the importance of moving fast by taking small steps when collaborating:

> "What seems to work is to involve the recipients from the parent company early in the process, and you make the project quite quick, you take small steps together with the startup, you try to get to a conclusion in 2–3 weeks, that's what we try to have as an aim."

In addition, the CIH needs to ensure that the recipients at the parent company have credibility, by using internal champions. These are trusted specialists within the parent company who can advocate for the CIH. Furthermore, it is important and necessary to communicate the results and knowledge learned from projects and collaborations through the CIH, not only internally to the parent company but also externally to startups and other organizations, in order to create the motivation to participate.

4.3.2. Mechanisms mitigating NSH problems

4.3.2.1. Creation of a knowledge sharing environment. This dimension centers on the creation of an environment where individuals in organizations collaborating through a CIH feel safe to share knowledge with each other. Two second-order themes were identified for the mitigating mechanisms of NSH: *Mutual confidentiality understanding* and *Use of appropriate safeguarding.*

Mutual confidentiality understanding. Being able to understand the difference between confidential and non-confidential knowledge is fundamental to mitigating NSH, where mutual includes all three organizations: the CIH, parent company and startup. When individuals in organizations do not know what they can share, they most often do not share at all. All organizations should consider assessing confidentiality before engaging in conversation. The CIH should encourage this assessment, as it will lead to a safer knowledge sharing environment. As the CEO and Co-Founder of startup Iota (R29) stated:

> "Think strategically about what knowledge you can leave with others and what you should keep for yourself, having that understanding before you approach these problems is the key to success."

We believe this is especially important when inviting technical specialists to engage in a POC, so all organizations and individuals know what knowledge will be shared and why. Lastly, when the CIH encourages other organizations to share its intentions on how to use shared knowledge, this will build trust among collaborating organizations.

Use of appropriate safeguarding. Organizations should be encouraged by the CIH to ensure that individual IP is secure before they engage in collaborations, to avoid undesired legal twists. Furthermore, the NDAs used for collaborations through the CIH need to be reworked and simplified and should preferably have a stepwise format, so that they only provide the protection required at each step of the collaboration. In addition, the NDA signing process at the CIH should be less formal and a natural part of the working processes, so that decision-makers, such as legal advisors, are easy to reach if specific paragraphs in the NDA need to be adjusted. Also, respondents stated that it is important to have designated employees at CIHs that have the authority to sign the NDAs without further approval. As a Business Developer at parent company Beta (R25) explained:

> "Make it easier in terms of who signs NDAs, it doesn't have to be some top manager, we have two designated people in each unit, and make it okay to sign them a little faster. Then find out what type of agreement you need. You can have a process map, if you want to do

this, and this is what you want to achieve, then you will need this agreement."

However, appropriate contracts will not solely build a safe knowledge sharing environment— having knowledge available from both the parent company and the startup is fundamental to pursuing collaborations among organizations through a CIH.

4.4. *Towards a framework for mitigating NIH & NSH problems*

Based on the inductive analysis, a framework illustrating how CIHs can work to mitigate NIH and NSH problems in knowledge transfer has been devised and is presented in Fig. 2. The framework is formed by deploying the themes and dimensions from the empirical analysis as building blocks, and is thus supported by the data structure presented in Fig. 1. When reading from left to right, the connections between causes and consequences are visualized by horizontal arrows, either as strong in black or as weak in grey. Mechanisms are shown as moderators, which influence the strength of the relationship between causes and consequences (i.e. they mitigate or weaken the consequences). These are illustrated with vertical arrows in the same color scheme. The framework is a visual illustration of the findings, and provides a contingency perspective on how to match mitigating mechanisms with causes and consequences.

Among the causes of NIH problems, *Obsessive control* and *Internal antagonism* lead to the most consequences, namely, *Lagging behind the knowledge frontier* and *Suffocation of external ideas,* thus indicating that these two causes and consequences may be the most critical. *Translate relevance of ideas* seems linked to the most connections between NIH causes and consequences, making it the most important mitigating mechanism to consider. That said, *Creation of mutual ownership* may also be a powerful mitigating mechanism, while *Exaggerated knowledge valuation* is another key cause of NIH problems, leading to *Lagging behind the knowledge frontier* (among other things).

On the other hand, *Confidentiality unawareness* is a cause of NSH problems that has strong connections to all key consequences, indicating that it may be the most critical cause. However, the consequence of NSH *Constrained problem-solving abilities* has strong connections to all causes, making it a critical consequence. Lastly, *Mutual confidentiality understanding* is the most important mitigating mechanism to consider, since it has the strongest connections between NSH causes and consequences. However, the *Use of appropriate safeguarding* can be a powerful mitigating mechanism, and *Depreciation of knowledge* and the *Desire to monetize knowledge* assets are key causes to consider.

However, the mitigating mechanisms of both NIH and NSH problems should also be considered simultaneously, since NIH and NSH constitute interconnected problems as CIHs take part in increasingly open innovation processes. These processes are characterized by the active transfer of technology both in and out through company boundaries. Therefore, the act of transferring knowledge among parent companies and startups through a CIH requires an explicit discussion about both NIH and NSH, since it is essential to mitigate both these problems for a CIH to operate effectively.

5. Discussion and implications

This article extends prior research on NIH and NSH problems in knowledge transfer occurring among organizations collaborating through a CIH (Berger and Brem, 2016; Fecher et al., 2020). As more and more large corporations create CIHs to facilitate knowledge transfer to and from partners, additional insights about organizing and managing CIHs are needed. Specifically, CIHs are created as bridges into innovative ecosystems (Walrave et al., 2018), yet often fail to meet the objectives set for them. NIH and NSH problems are at the core of such failures. The existing literature has identified several mitigating mechanisms for NIH and NSH problems in more general knowledge transfer settings, but has so far not provided specific insights into how they play out in the context of CIHs (Aquilani et al., 2017). Our study helps close this gap by studying the causes, consequences and mitigating mechanisms of both NIH and NSH. The study is particularly relevant as more CIHs are established, and as more firms move towards increasingly open innovation processes involving the active transfer of technology across firm boundaries. Moreover, Monteiro and Birkinshaw (2017) have investigated knowledge transfer between CIHs and parent companies but have

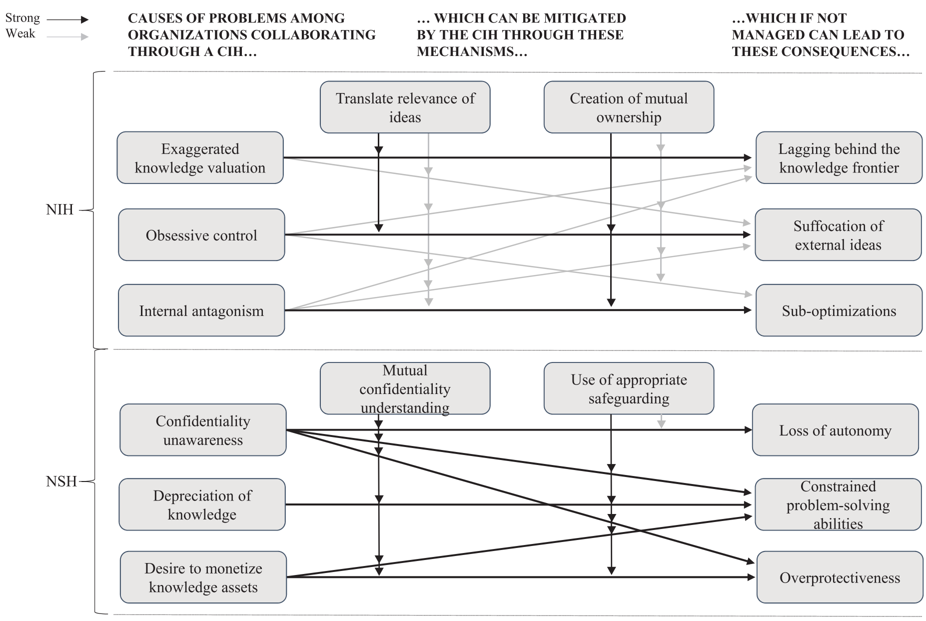

Fig. 2. CIHs mitigating NIH & NSH problems.

not provided insights into the knowledge transfer among CIHs, parent companies and startups. This increased interest in active technology transfer brings the problem of negative attitudes to the forefront (Aquilani et al., 2017; Chesbrough, 2003; De Araújo Burcharth et al., 2014).

5.1. Theoretical implications

In response to the sparse and largely conceptual research on NIH and NSH problems in knowledge transfer among organizations collaborating through a CIH, our article contributes to prior literature in the following ways.

First, we contribute to the conceptual understanding of NIH and NSH problems in the context of CIHs involving multiple organizations in an ecosystem setting (Adner, 2017; Banc and Messeghem, 2020). Prior literature has so far mainly focused on these two problems in a two-sided context, i.e. in dyads (Antons et al., 2017; Antons and Piller, 2015; De Araújo Burcharth et al., 2014; Hussinger and Wastyn, 2012; Kathoefer and Leker, 2012). By studying NIH and NSH problems in a context where multiple organizations collaborate through a CIH, we not only find new causes and consequences for NIH and NSH problems, but also new insights into the corresponding mitigating mechanisms for both problems. By doing so we answer the calls from Hannen et al. (2019) and Banc and Messeghem (2020) for an ecosystem perspective when studying NIH in knowledge absorption processes. For instance, the cause of NIH that we have labeled *Internal antagonism* seems neglected in prior literature, and clearly has its roots in an ecosystem context. Internal antagonism could also be interpreted as a sign of internal and individual competitiveness within an organization. Just as Hussinger and Wastyn (2012) argued that NIH occurs when transferring knowledge between competitors, our findings emphasize that organizations collaborating through a CIH could sense a strong competitive situation even if they belong to the same organization. Competition is indeed a key issue in ecosystems (Granstrand and Holgersson, 2020).

Likewise, the cause of NSH that we labeled *Depreciation of knowledge*, which could be interpreted as a sign of fear of not being an attractive partner when collaborating with external organizations, seems to have been overlooked in prior literature. Organizations collaborating in ecosystems seem not only to be afraid of sharing too much, but also of sharing knowledge that might not be as appealing for others to absorb. This might be an effect of limited prior experience with outward technology transfer (Hoegl et al., 2011). Another finding that seems neglected in prior literature is the mitigating mechanism of NSH that we labeled *Mutual confidentiality understanding*. This underscores the importance of experience in knowledge transfer in an ecosystem context and aligns with Aquilani et al. (2017) in developing a strong sense of trust and openness when engaging in knowledge transfer in a CIH context. Mitigating NIH and NSH problems in ecosystem contexts may therefore be more complex than it has been depicted in the literature thus far. And in light of increasingly open innovation processes (Adner, 2017; Chesbrough, 2003), with multiple organizations involved, NIH and NSH problems need to be studied in ecosystems rather than just between two entities. Even though a CIH is established to create de-biasing bridges among collaborating organizations (Berger and Brem, 2016), the bridges among all organizations will still be guarded by the negative attitudes resulting from NIH and NSH biases. We thus propose that the NIH and NSH literature should better incorporate multi-actor collaboration involving intermediaries.

Second, our results shed new light on knowledge transfer in two-way reciprocal processes, where NIH occurs on one side of the process and NSH on the other (Chesbrough, 2003). In prior literature, NSH is largely overlooked and potentially underestimated (Antons and Piller, 2015; Hannen et al., 2019), although the process of sharing knowledge is heavily affected by the NSH problem in a CIH context (Hannen et al., 2019). The action of absorbing knowledge by one firm thus requires the fundamental action of sharing knowledge by another. For example, one organization's NIH attitude, such as *Obsessive control,* could lead to another organization's NSH consequence (such as *Loss of autonomy)*. While our study was not designed to perfectly match NIH and NSH problems, it underscores that individuals adopting boundary-spanning roles may act to identify and mitigate both NIH and NSH attitudes when transferring knowledge across organizational boundaries. Individuals at CIHs typically assume boundary-spanning roles (Monteiro and Birkinshaw, 2017; Tracey et al., 2018). To improve knowledge transfer in ecosystems as well as in dyads, we need to study NIH and NSH problems in more depth, and—most importantly—*simultaneously*. Our study is a step in that direction, but we call for future research to further advance the understanding of how these two problems interconnect in knowledge transfer.

Third, our research contributes by providing new causes, consequences and mitigating mechanisms for both NIH and NSH problems, and further delineates how certain consequences can be mitigated by specific mechanisms. Any organization involved in technology transfer needs to manage conflicts and/or deal with the resistance that follows from these problems (Calof et al., 2018). However, as prior literature has mainly provided, and adopted, one-fits-all mechanisms for both NIH and NSH problems, our findings provide more fine-grained knowledge of how to best mitigate NIH and NSH problems. For instance, Aquilani et al. (2017) and Longo and Giaccone (2017) argue that the mechanism to build a strong sense of trust and openness can mitigate both NIH and NSH problems at the same time. While these results make sense on an overall level, our research underscores that the key mitigating mechanisms for NIH problems may be different from those for NSH problems. In other words, even though the two problems are connected in open innovation processes (Chesbrough, 2003), they seem to have fundamentally different root causes and consequences, which need to be considered in choosing appropriate mitigation mechanisms. This finding sets out a contingency perspective for thinking about how to better mitigate NIH and NSH problems, and extends prior literature on CIH-related NIH and NSH (Aquilani et al., 2017; Longo and Giaccone, 2017).

5.2. Managerial implications

A corporate innovation hub constitutes a specific governance structure, where the hub largely decides who is allowed to participate and how participation takes place (Remneland Wikhamn and Styhre, 2019). The causes, consequences and mitigating mechanisms we have identified can thus be used to improve this governance structure by detecting, mitigating and/or preventing NIH and NSH problems. CIH managers and collaborating organizations—startups and parent corporations—can benefit from the framework, which provides a guide and a blueprint for proactively preventing tensions and misunderstandings among collaborating organizations. Specifically, the results have three different implications. First, awareness of the causes identified can assist all collaborating organizations to identify NIH and NSH problems in and among a group of organizations collaborating through a CIH. They also provide a tool for self-assessment and group discussion, e.g. on whether low confidentiality awareness is a problem, how that manifests itself, and what potentially could be done.

Second, CIH managers, in particular, can seek to apply mechanisms for specific causes they have experienced—bearing in mind that NIH and NSH problems need to be mitigated independently—where some mechanisms seem more appropriate than others, depending on the cause. For NIH, the mechanism *Translate relevance of ideas* may be suitable for addressing *Exaggerated knowledge valuation* and preventing the consequence *Lagging behind the knowledge frontier*. And for NSH, an example would be to use the mechanism *Mutual confidentiality understanding* when mitigating *Confidentiality unawareness* and preventing the consequence of *Constrained problem-solving abilities*. In addition, the causes and consequences can be used by managers at CIHs to ensure legitimacy when advocating for the importance of CIH activities, including promoting the value proposition of such activities to internal stakeholders. By doing so, it can become more than just an “innovation theatre”.

Third, we believe our results will also be applicable to parent companies and startups. Specifically, these organizations can increase their awareness of how their behavior can affect collaborations through CIHs. We hope that, by becoming more aware, both types of organizations will seek to implement their own NIH and NSH problem-mitigating mechanisms when collaborating through a CIH.

5.3. Limitations and future research

This study comes with a couple of important limitations. First, all investigated CIHs are active in exploring technologies related to future transportation solutions. This reduces generalization of the results, which calls for future studies in other industries to understand the causes, consequences and mitigating mechanisms for NIH and NSH. It is important to keep in mind that the transportation industry is somewhat conservative about leveraging external innovation (Hjalmarsson Jordanius et al., 2019), which makes it a good case for studying NIH and NSH problems. Second, there are other types of organizations collaborating through a CIH in addition to those investigated in the current study (see Pauwels et al., 2016; Salomaa, 2018; Schuh et al., 2017). These include academia, investors and government, and this implies the need to further our understanding of NIH and NSH problems in a broader set of organizations collaborating through a CIH.

The inductive case study also has important limitations as a method, namely a limited sample and a heavy reliance on key informants. Additionally, even if the opinions, ideas and thoughts of participants in the innovation system (CIHs, parent companies, partners, etc.) are important, the real impact may differ from these opinions, ideas or thoughts (Mees-Buss et al., 2020). To offset these weaknesses, we triangulated the results, but we also encourage future studies into NIH and NSH problems in and around CIHs which will encompass a broader set of organizations, across other industries and technological domains, and with different research designs. Our research lays the basis for further quantitative research which can validate the relationship between the causes and consequences while testing the effectiveness of the mechanisms to mitigate NIH and NSH.

Moreover, we encourage more specific studies into the actions that different types of organizations can take to mitigate NIH and NSH problems. Different types of organizations may vary in agency, motivations and capabilities. Another topic ripe for future research is that of the interrelationships between NIH and NSH. In the current study, these were treated largely as independent problems, but in open innovation processes of a coupled type, which are characterized by the simultaneous transfer of technology in multiple directions, more research is needed into how NIH affects NSH and vice versa.

Next, our findings indicate that NIH and NSH problems may be more prominent when transferring domain-specific technical knowledge than procedural knowledge. This aligns with Schuh et al. (2017) and Antons and Piller (2015), who argue that the type of knowledge transferred impacts NIH problems. It would be useful to investigate whether this also holds for NSH problems, and whether the causes, consequences and mechanisms differ depending on which knowledge type is being transferred. In addition, future research should dive deeper into the concept of NSH and its constituent elements because causes, consequences and mitigating mechanisms may differ depending on whether the problem arises in the selling or sharing of knowledge or technology.

Finally, some CIHs seem to struggle with striking a balance between being independent from the parent company and not being disconnected. When striving for independence, the CIHs often become isolated without the support of the parent company, which in itself can generate NIH and NSH problems. Further study of this problem is particularly relevant, as an ever-increasing number of technology transactions go through CIHs.

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Paper E

HOW COVID-19 ENABLED A GLOBAL STUDENT DESIGN TEAM TO ACHIEVE BREAKTHROUGH INNOVATION

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ABSTRACT

This is a qualitative single case study of a geographically distributed student team that experienced a quite different graduate course, compared to previous year's. This was due to the restrictions placed upon them following coronavirus lockdowns. With already ongoing research, and continuous development of the course, the authors had documented individual reflections and identified patterns and behaviours that seemingly determined the quality of the end result, as well as the students expectations and experiences. Semi-structured interviews, surveys and the author's individual reflection notes were already in place as part of the larger research scope and when the student team during the covid-19 year showed unexpected performance and results, the authors decided to pause the larger research scope and focus on this unique single case and capture those learnings. Not knowing how the Covid-19 situation evolves and leaning on insights from previous years, as well as this unique year, the aim with this paper is to describe the unique Covid-19 year amd share knowledge that can help improve and evolve the development of this longlived collaborative graduate student course, and other similar distributed team contexts.

Keywords: Design education, Case study, Teamwork, User centred design, Design learning

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1 INTRODUCTION

To prepare graduates for working life, some engineering programs field curricula that implement problem-based learning (PBL) with design thinking principles, in collaboration with international companies and institutions, to realistically train students in real-world problem-solving practices (Jackson & Buining, 2011). One example is the ME310 graduate course at Stanford University (Carleton & Leifer, 2014). Students are trained in human-centred, design thinking principles to address wicked problems in distributed teamwork mode, progressing iteratively in divergent-convergent cycles of ideation, prototyping, and testing (Dym, et al., 2005). Industrial partners present challenging project prompts that require students to use creative, analytical, and collaborative abilities to develop and produce their solutions to highly complex and ambiguous problems.

This paper, written from a teaching and a corporate perspective, focuses on the cohort consisting of Stanford University, Blekinge Institute of Technology (BTH), and Volvo Construction Equipment, a subsidiary of Volvo Group that develops, manufactures, and markets equipment for construction and related industries globally. The two teaching teams form local teams of students with 3-5 students each to jointly address a corporate prompt, teach them design thinking principles, and coach them through the process. The goal is to provide a learning environment that entices students to independently navigate the innovation landscape in the skilful hunt for the next "big idea" (Steinert & Leifer, 2012) thus crossing the metaphorical threshold towards becoming design thinking engineers. Exhibiting exceptionally good aptitude means that the team achieves what is called "triple wow", meaning breakthrough performance along three complementary dimensions: design, engineering, and business model.

The authors, representing the teaching teams and the corporate, formed a supporting cohort, that observes, supports, and coaches the teams through their triple loop learning process (Leifer & Steinert, 2011). Promising and concerning team behaviours are observed and shared among the cohort, sometimes leading to encouragement, gentle nudging, or more explicit interventions. A mild form of intervention that has proven to be effective is to remind the team to ask themselves WHY and letting those answers guide them in the right direction. ME310 is a substantial commitment both financially and effort-wise, and because of this, rich documentation is generated by all involved, to prove value to executive management and to provide qualitative data for research. The ambition has been to reflect and take stock of what has gone well, what could have been done better, and what might improve future iterations.

This became particularly interesting during the academic year 2019/2020, where the fall and most of the winter quarter offered the usual observations, but when the coronavirus pandemic dawned, few things were normal and based on previous year's data this year's students would not be able to deliver a triple wow. The team exhibited team dynamics and distributed collaboration characteristics that have been proclaimed as mere potentials (Larsson, et al., 2003) and as they achieved an unexpected "triple wow", the authors decided to pause other related research and explore what lessons can be drawn for following years, and future research.

Hence, the objective of this paper is to investigate an unusual ME310 year from a backdrop of previous "normal" years to understand what new insights could enable triple-wow performance from student teams.

2 BACKGROUND

ME310, a graduate school course at Stanford University's Mechanical Engineering Program, was first launched in 1967 and might be the world's longest-running engineering design capstone course (Carleton, 2019) featuring masters' students in mechanical engineering and adjacent fields from Stanford and international partner universities, one of them being BTH in Sweden. It also serves as a study case and testbed for academic research, mainly for the Center for Design Research at Stanford University (Carleton, 2019), offering insights about team dynamics, global networked innovation etcetera (Carleton & Leifer, 2014). Stanford is the "epicenter" of the global network of schools, companies, and coaches that are affiliated with ME310, and the course combines interdisciplinary teaching and problem-based learning for engineering design. Every school brings a unique strength and corporate sponsors provide funding and project prompts. A diversity of perspectives and skills, an iterative design process (Lande & Leifer, 2009), a balance between deep reasoning questions and generative design questions (Eris, 2003), and positive team dynamics (Jung & Leifer, 2011) maximizes the chances of breakthrough innovation.

The learning objectives of the course are to have students 1) produce a pre-production proof of concept prototype of a refined solution from a given prompt, 2) be able to develop and evaluate engineering requirements, 3) foster team building and teamwork skills, and 4) develop individual skills such as project management and planning (Lande & Leifer, 2010).

The course syllabus is oriented on three workstreams (Figure 1) that coincides with the three quarters of the academic year. As the course begins in September, the Stanford students spend the first few weeks attending lectures in design thinking, training in potential solution technologies (e.g., microcontrollers, system on a chip, single-board computers), building a course culture and put emphasize on user-centric design through designing, building, and racing cardboard bikes, "the paper bike design exercise". In time for the corporate project start, the project teams are formed. The BTH students work on ME310 as part of their final-year master thesis. Only having to field one team of 3-5 students, they are selected based on performance in a one-day hackathon-style design event, where they work on a wicked-problem challenge, with supervision and coaching from the teaching team. Coaches observe to gauge who copes with ambiguity, addressing the challenge with a mix of creative and engineering mindset to tell a compelling story of their prototypes. The ones that perform best are offered to join. The students work iteratively in divergent and convergent modes to turn concrete empathic observations of user "pains" into prototypes that are challenged and proven through testing.

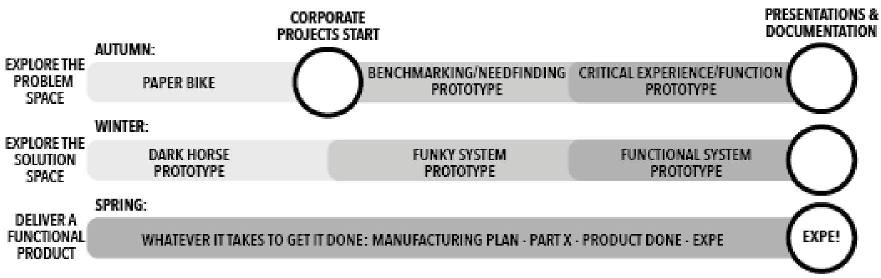

Figure 1. ME310 syllabus yearly overview (adapted from Schar, 2012)

The corporate project prompts are presented to the global teams in October. The first quarter is mainly focused on exploring the problem space, where the global team perform its first iterations of need-finding and benchmarking as well as get to know each other through team building activities. Here, uncovering the user's "jobs-to-be-done" (Ulwick, 2017) and building "the right it" (Savoia, 2019) is predominantly in focus. There is a bias towards action where the students demonstrate learnings via a range of prototypes. Examples include the Critical Experience and Critical Function Prototypes, which are only just as high fidelity to enable a tester to offer feedback and the team to infer insights from testing them, thus simplifying any decision to discard them in search of answering further questions.

At the end of the first quarter, the team documents and presents their findings in a report, enabling feedback and grading from the teaching team, and a decision on which problem sets to converge on.

The middle part coincides with winter quarter, where the team should take their understanding of the problem further into design space exploration, with a view of reaching a convergence towards a concept that should be their final solution. Here the first iteration deals with the so-called Dark Horse prototype (Bushnell, et al., 2013). The team aims for an audacious goal and where success is measured not by a positive outcome, but by the learning derived from testing. Then the students move towards a system view of their prospective solution, first with the Funky prototype, where they hack things together with bits and pieces and duct tape to keep learning about what to develop without worrying too much about the details. The second iteration of the Functional prototype is more polished and closer in resemblance to a final system. When or if they run into a dead-end, they can pivot towards some other solution space. Therefore, the team must maintain focus on need-finding and benchmarking throughout the project. The winter quarter also ends with a report, enabling feedback, grading and team discussions about what concept to converge on. Those discussions are taken into spring break when the team convenes at the BTH campus and visits the corporate for a presentation and conversation with an extended group of company staff. During this period, based on deeper discussions and from feedback from the partner, the team decides what concept to converge on.

Moving into spring quarter, every focus is on the delivery, meaning bringing the solutions to a finished presentable prototype stage. For the final event, the EXPE (Stanford University Design EXPErience), they must consider how to present the solution and convince the audience about the value the solution offers. Not only does the EXPE prototype need to be real and realistic, it also needs to match well with the identified user needs, the selected problem space and the user desirability, business viability and technical feasibility. Telling the story, also considering business and systems factors, is almost as important as presenting a well-engineered product, so the team also needs to design and print posters and brochures, prepare, and rehearse a presentation, and create a demo booth for the design fair.
On the first Thursday of June, EXPE is held, with a broad array of onlookers, ranging from corporate liaisons, other academics and students, and Silicon Valley venture capitalists. The whole project is then wrapped up in the final documentation.

2.1 Why ME310 matters to the corporate partner

Every year the ME310 student teams are given corporate project prompts with broad challenges, relevant to the corporate's strategy and vision, and are guided through a design thinking-based work process, much different from the corporate's own stage-gate-based product development process (Cooper, 2009). This approach enables teams to see the complete, holistic user context, unbiased by existing offering limitations, a perspective not based on preconceived industry understanding or existing customer's feedback and therefore both the problem space and the solution space is larger than what it tends to be for the typical corporate employee. The corporate's prompts are designed to be complex and explorative, posing questions in areas where straightforward answers do not exist, albeit focusing on contexts (e.g., urban mining, autonomous machines, electrification, connectivity, waste and recycling industry, safety) that are of interest for future value propositions. These prompts are seen with some scepticism within the corporate, with a long history of thinking in terms of products rather than integrated product-service systems. By having the team of students, that are not at all biased by existing business, explore new possibilities of solutions, it is possible to learn many innovation opportunities beyond the initial expectations. By engaging and interacting with the students throughout the school year the company can learn about the context, the users, the problem space, different conceptual solutions, engineering tools and methods, communication platforms and collaboration styles. ME310 participation is for a corporate a learning experience, a networking experience, and new business opportunities.

2.2 Observations from previous years

The authors have interviewed the students during several years with the aim to understand distributed team dynamics versus performance, and individual expectations versus experiences. This material is organized throughout the school year timeline, forming a general "team journey map", which is part of future work. During previous "normal" years, the following general patterns are identified:

- Teams spending time with each other outside the schedule during the week when they are gathered at Stanford are better at staying in touch throughout the year and are therefore able to utilize the full team's insights and capabilities better. The years when team members only show up occasionally for the hang out time, and seemingly want to be elsewhere, reflected that lack of connectedness by more frustration and conflict, or disconnect later in the year.
- Teams that do not get the "one global team" feeling will not reach as far as the ones collaborating throughout the journey. Some teams ended up with one Stanford delivery and one BTH delivery and connected these through storytelling.
- Teams seem to reach further with their solution when the final convergence does not happen until the Stanford students visit in Sweden during spring break, therefore any attempt to converge prior to the spring break are challenged.
- Mutual interest for each other's work and respect for each other's competences within the local teams, and in the global team significantly increases the quality of the final EXPE delivery, why the supporting cohort made sure the teams set up lightweight knowledge sharing technologies (Bertoni & Larsson, 2011) and conduct joint meetings from the get-go.
- The quality of the EXPE delivery is higher when the full team engages in intense, co-located collaboration to get the showcase prototype and the auditorium presentation ready for EXPE. This meant that the BTH students arrived at Stanford 3-4 weeks prior to the EXPE. An intense

and memorable experience for the team, and a significant time and money investment for all involved.

- Teams with a few individuals being appointed, or self-appointed, as leaders tend to lose a few individuals in the teamwork, so the team breaks up in subgroups. Teams where all feel equally responsible tend to stay cohesive and involved throughout the project.
- Teams that take on an ownership role, and act as this is **their** project, **their** shared accomplishment and do not just accept what the teaching teams are telling them become more cohesive and end up prouder and more satisfied with their experience.

3 RESEARCH APPROACH

This paper reports on a qualitative single case study (Yin, 2009) into an ME310 global engineering design student project between Stanford and BTH. The aim was to investigate touchpoints and reasons for aspects that deviated from the normal course of events because of the restrictions placed upon the students following coronavirus lockdowns.

During the year, as in previous years, the researchers have, as part of being in the supportive cohort, followed the students' work, information creation and parts of their communication. This information, as well as the interactions with the students, were the foundation for reflection notes, covering this year as well as the previous seven years, which the authors wrote independently and shared. As this year was unique the authors decided to perform semi-structured interviews with 7 out of the 9 students. The interviews were conducted in retrospect shortly after the project was concluded. The in-depth insights from the 2019/2020 year were compared with the identified general patterns from previous years, and this paper is presenting an initial Covid-19-year specific result, with more to uncover.

4 OBSERVATIONS DURING THE COVID-19 YEAR

ME310 in 2019/2020, started as any other year, with four Stanford students and five BTH students. The global gathering at Stanford's campus took place late in the fall semester, with lectures, team collaboration and presentations. The winter semester begun the same way as previously, with a global team showing promising team dynamics and performance, like the highest performing teams before. In February the coronavirus pandemic caused all Stanford students' trips to their global partners to be cancelled. This eliminated the usual visit to the corporate's headquarter, a previously identified important instance leading to the final convergence. Next pandemic effect was that all Stanford students were sent away from campus and continued their education remotely, in lockdown, geographically dispersed across the United States, and with limited resources for prototyping. The BTH students were also moved to distance learning, but with Sweden's less restrictive corona strategy they could do some prototyping in their kitchens until the campus lab facilities were opened, shortly before EXPE. This situation was devastating for the team that already felt they were behind schedule. They had not converged and were prepared for intense, focused work during the time together in Sweden - and now, in their homes they all expressed disappointment and hopelessness.

4.1 The Beginning phase

The prompt, focusing on "the future of waste industry", with the addendum of the Volvo "triple zero" vision (zero accidents, zero emissions, zero unplanned stops), was presented to the global team in October and was considered very wide, which the students retrospectively understood was intentional. As they found it difficult to make sense of, they simply got started riding along with garbage trucks and looked for different user pain points and needs. In their search for the "golden nugget", they explored numerous areas and the challenge was to decide when they had done enough research and should move on. They demonstrated good connectedness and worked diligently with the problem space exploration, and shared insights openly and frequently. The team was deep into the need-finding at the time for the global summit and presented a first functional prototype, targeting a user persona far outside intended industry segment. Nobody in the team were committed to that solution, and expressed stress over not yet being close to finding their "it" (Savoia, 2019). This did not worry the surrounding cohort, as early convergence has shown to be more limiting than late convergence when the team has found their "it". The team was despite their worries acting as one cohesive global team, loyal to each other and highly motivated. Below quotes from the team members during the beginning phase provides a good illustration of the team dynamics at that stage:

"The Swedes came over in late November and we already felt like one team because of all the need-finding and benchmarking we had done and shared."

"Without that kick-off week, we wouldn't have any collaboration at all. Just a few meetings here and there."

"And when we are one global team, then you cannot compete with each other."

4.2 The Middle

During the beginning of the winter semester, the students at the two schools usually struggle to collaborate effectively. While the BTH students are challenged to have solid reasoning behind every concept they explore, and consider integrated product-service-systems, and circularity, the Stanford teaching team is pushing for rapid physical product prototyping with quick iterations. The differences are required as the academic education in the countries is different and causes confusion between the student teams, which the students describe like this:

"The Stanford teaching team was constantly pushing for deliverables and convergence while the BTH teaching team pushed for critical thinking and further exploration, more divergence. For us, as one team this was stressful and confusing."

"During the winter semester we didn't collaborate, because of the differences in courses, but we kept informing each other, and encouraged each other, for us at Stanford it felt like we were only satisfying the Stanford teaching team's requests."

The team had several concepts going on in parallel, and these were generating further questions regarding desirability, feasibility, viability, scalability - and sustainability. They were late with convergence compared to other teams, and worried about a time-pressured spring quarter. Then the coronavirus hit, and with an already challenging situation regarding convergence and now not getting together in Sweden as they had planned for and looked forward to, they felt despair. At first, the Stanford students planned to rent a place to stay at to get focused collaboration time, but when they were sent away from campus, they ended up far apart. The BTH students also had limited access to campus, with online education, but stayed in the same city.

All this could have been detrimental for the team's progress but turned out to work well for them. Thanks to the struggle with convergence, they were all focused and continued to work intensely around the clock to get to the decision. Already oriented towards the waste industry and with one concept being water-soluble packaging, the situation with the coronavirus causing shortage of personal protection equipment provided a new both clear and urgent direction for them. All students described afterwards a strong feeling of epiphany, finally they had found their "it". The team reached out to connections within the waste industry to learn if the solution had potential and were encouraged to continue with this solution. Waste management workers use 3-5 pairs of gloves per 8-hour shift and by using water-soluble polyvinyl alcohol (PVA) gloves, facilities could reproduce fresh new gloves after contamination, locally in their own circular mini factory. Unlike single-use gloves, the PVA based ones will be non-toxic and biodegradable. A circular system reduces the amount of landfill caused by PPE, in-house glove manufacturing decreases dependence on external supply chains, and a mobile production system could allow gloves to be made anywhere.

Below are a few quotes from interviews with the students, regarding the convergence.

"We postponed convergence because we didn't LOVE any of our concepts."

"We spent 5 hours a day for 2-3 weeks just trying to push concepts further, and none of them felt right, then covid hit, gave us the PPE crisis and that was exactly what we needed, suddenly we found our "IT", we all felt it, and knowing that we were late with our convergence we were so relieved and also knew that we needed to move quickly, we all had a strong sense of urgency."

"We made many pivots during the journey. When Covid-19 appeared with all the media reports about PPE shortages we already had an idea about a circular system, but for packaging material. We struggled a lot with this and wanted to keep working on it, and when the pandemic came about, we thought - why isn't there a circular system for health care PPE?"

"Selecting this concept, which was directed towards a major problem in the wake of Covid-19 we also felt an urgency not just for our studies, but also to deliver a solution that provides something that the world needs."

"We were already mobilized, worked closely together and had connectedness like no other team, covid couldn't stop us."

"We felt this is our IT and the deeper we went into that problem space with both hospitals and the waste industry it was so clear it made sense."

4.3 Delivery phase

Once the decision was made the team got busy designing, building, and testing prototypes and preparing for the first ever online EXPE. Previous years the teams that get together on Stanford campus and collaborate intensely to prepare for the EXPE day are the ones that reach the farthest. This year there was no on-campus time to hope for, and for this team, there was no need. This team showed no tendency of using the pandemic as an excuse.

Thanks to their late convergence they had a strong sense of urgency, were mobilized and shared tasks - even utilized the time differences to their advantage. It was also observed that in this team nobody was in charge, at any point. Instead, the team members were dynamically taking turns and if someone needed to take a break, another team member stepped in and if someone seemed disengaged the team naturally reengaged that individual. Another observation throughout the year was that there were no critical comments about the other school or the other students. Maybe the pandemic came in and played the role of an evil enemy, galvanising them? Of course, without the usual social life on their respective campuses, the students had more time for the project and more time to connect with teammates in different time zones. The students' experience of the delivery phase is reflected in the following quotes:

"Thanks to the lockdown we broke up the Stanford team, and became one global team, and then we worked around the clock."

"We worked task-oriented so when somebody went passive, he or she would get tasks and that brought them right back into action."

"You need a bit of information to be able to discard, in the same way as when you select to keep something. A lot of work is down to doing research."

"The situation forced us to collaborate in other ways. Otherwise, we would have the Swedes meeting every day and then we would have discussed it once a week with the Americans. Now we had meetings every other or even every day to bounce ideas with each other."

"We were the ones that could build stuff since we had access to facilities and tools. But that didn't mean that the Americans were disconnected from that part of the project. They were drawing the cad models, and then we built what they had been drawing. We were always working on the same project, even though everyone didn't have the same opportunities to realize the machine. Some people found joy in doing material testing and investigating material properties, then they did that. The ones who liked CAD could do that. So, we utilized what people enjoyed doing."

"Keep everyone emotionally connected to the prototypes that are built in Sweden – even when you are sitting in Hawaii and have been doing some CAD models, you are still involved."

This team demonstrated strong connectedness, and a positive attitude towards each other, even during stressful, challenging times (Jung & Leifer, 2011). The authors were able to observe the mix of formal task-oriented interaction together with informal communication (Törlind & Larsson, 2002) during the most intense preparation work before EXPE. They managed to deliver a near-perfect EXPE experience, in terms of presentation, in terms of online marketing material and in terms of a fully functioning prototype, and they did it online, during a pandemic.

The students themselves said:

"I was so proud of us, we had a needed and sustainable solution, and we had tested all aspects of it."

"It was a rough year, we had moments when we thought we were failing when we felt that we weren't meeting the expectations from the teaching teams and the corporate, but we kept working and, in the end, we felt proud and accomplished."

"During the EXPE presentation people thought this was a prototype and solution that was timely, given Covid-19, but also for the future where these materials are problematic since it represents an old way of thinking where you produce, use, discard and never see it again."

4.4 Concluding the year

At the end of the school year, the students looked back at a very rewarding experience and the work with their solution continues. During the retrospective interviews with the students, they all expressed pride and gratitude, and they all mentioned that post Covid-19, they will get together and celebrate an outstanding accomplishment during an outlandish year. A few reflections by the students below:

"We spent two-thirds of the year just dismantling the problem space and that was something I really appreciated."

"Such a great learning *experience, both the design thinking modes and the team dynamics, especially since we had such a good team."*

The Covid-19-year ME310 experience provided perspectives and insights that are partly captured in this paper. This global team of ambitious students started off the year in an expected promising way, got their expected course journey dramatically disrupted by the global pandemic and were after that surprisingly successful. They did not use the pandemic situation as an excuse, they pushed themselves and took care of the team spirit, and their full-year result was what we call a triple wow. Previous year's observations showed that this team was likely to fail, but they didn't.

5 CONCLUSIONS

Guiding a geographically dispersed student design team working at the forefront of innovation with wicked problems in capstone courses is anything but piecemeal. Many actions that orchestrate the project and team are based predominantly on reflections on the actions undertaken with experience, as an expansion on design thinking theory, which is accumulated for several years. Every year more lessons are learned, some of them challenging previous truths, and the authors' ambition is to address and analyse those deeper to develop recommendations for other engineering capstone courses. The year affected by the coronavirus gave new surprising and unexpected insights that overthrew some previous "truths" and assumptions about what ought to be achievable under those circumstances. Sending students into lockdown and taking away their prototyping realisation resources ought to be detrimental to the performance and morale in the team. But, as this team demonstrated, the global crisis provided purpose, momentum, and a sense of urgency, and the team was able to reap the benefits of being dispersed across even more time zones to coordinate efforts according to who could best address each issue. This was enabled by a solid build-up of the global team, bonding to build trust already before the situation changed, and therefore not directly comparable with previous or any following year. This team demonstrated the following, throughout the year, before and after the coronavirus hit:

- They liked each other, all of them enjoyed spending time together outside the schedule. The early together-time built trust and respect, which is easy to do when meeting in person. The core function is that they need to hang out in a way that it is not forced upon them so they just gladly will leave at the first opportunity, which will be a challenge to facilitate when restrictions are at the outset.
- They felt equally responsible, nobody was appointed or self-proclaimed as leader. The nature of the restrictions and their late mutual convergence fuelled momentum throughout the team, utilizing the strengths of what everyone could offer. Everyone leaned in and when someone ran the risk of falling out, their friends helped. This sense of urgency and respectful division of tasks should also be sought from the cohort in normal years when the external factors may be more beneficial.
- They spoke highly of each other, even during challenging times, and jointly utilized the entire team's different skills and energy levels to get every task done. It was clear that they "suffered for" each other and while finding a common goal in the PPE shortage, they also found common ground in having a "common enemy" in their perceived scepticism from the teaching staff. When reflecting on actions to take, the cohort can play the devil's advocate on the process.

- They utilized time zone differences and the extraordinary geographical distribution as opportunities. By working around the clock, relaying ongoing work to each other until the task was completed, they were possibly even more productive than a co-located team would be.

In the spirit of Professor Bernie Roth, cofounder of Stanford d.school, the following poem, written by ME310 Professor of Mechanical Engineering Mark Cutkosky, provides comforting words for students in despair (Sheppard, u.d.):

"The days are growing short and grey. The project isn't what you'd thought. The teaching team wants C.F.P.s, but your sponsor has his own ideas (some are reasonable, some are not). Too little time, too many questions, too many constraints. You're at a loss… But HEY, it's O.K. because… you're the BOSS!"

6 FUTURE WORK

With merely one year and one team experience of a pandemic affected ME310 project, it is not possible to conclude that these learnings are repeatable. They challenge previous year's hypotheses and future work will include an exploration on whether a more structured and real-time sharing of observations among the cohort would benefit the cohort calibration, to tailor coaching and facilitation, each year.

In the future work the authors also aim to revisit all previous year's documentation throughout the three- semester course "journey" and map out student experience and team performance data to further develop understanding of what makes teams achieve triple wows and what causes glitches in the teams. The team journey map, connected to the previously defined triple loop learning concept (Leifer & Steinert, 2011), and the importance of T-shaped individuals, will be part of a research framework for the authors to explore how to develop engineering education further.

It would also be of value to explore the evolution of the definition of deep competence, and potentially provide insights into how globally distributed teams can tackle today's and future generations most critical systemic wicked problems, related to climate change, social justice, and sustainability.

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Paper F

Guiding Global Innovation Teams on their Exploration Journey: Learning from Aspiring Engineering Students

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This study investigates how to monitor the progress of globally dispersed innovation teams engaged in explorative projects in an engineering graduate course with problem-based learning. Using insights from a longitudinal study, the study aims to improve individual learning and team performance by increasing the likelihood of success. Early observations revealed that the best-performing teams had similar patterns in learning experiences, leading to further research to understand how the supporting cohort, who provides the problem, project expectations, and preconditions to the team, can positively impact both the team's performance and students' learning experience throughout the course. In addition to providing a deeper understanding of innovation team performance, the study proposes two lightweight tools to serve as shared visual representations of the team's exploration journey, which can assist the supporting cohort in guiding and improving team performance and student learning. This research is essential as it enhances our understanding of facilitating successful team performance and individual learning in globally dispersed innovation teams undertaking explorative projects. The proposed lightweight tools provide practical solutions to improve the supporting cohort's ability to guide and impact team performance and individual learning experience. This study has implications for academia and industry, especially organizations relying on innovation teams to drive their competitiveness and success. Finally, the findings of this study could inform the design and delivery of future problem-based learning courses focused on innovation and team performance.

Keywords: Problem based learning, engineering design, innovation team, globally dispersed teams, exploration, design thinking

1. Introduction

Breakthrough innovation might be the outcome when an innovation team has the necessary exploration and engineering skills available and utilizes those effectively throughout its explorative project journey, a capability that can be trained in higher education courses through problem-based learning (PBL) [1]. The problems the teams address can differ in nature, complexity, urgency, and severity; even wicked problems can be addressed [2]. Through a longitudinal study of student teams carrying out explorative innovation work in a PBL-style engineering graduate course, the authors investigate how a supporting cohort, i.e., a group of people providing preconditions, a problem statement, contextual information, theory, training, coaching, and feedback, can guide a team, even when both the team and the supporting cohort are globally dispersed. The guidance from the supporting cohort should not be provided by prescribing the exact path to follow but by walking the path with the students and guiding them in navigating pitfalls and seizing opportunities on their learning journey. The studied teams participated in a nine-month-long capstone course [3, 4] where problem-based learning was applied. The course has been running since the 1960s with the pedagogical mission to let student teams learn by doing while solving real problems provided by industry sponsors. Since the early 1990s, student teams have been globally dispersed by combining one group from a US engineering school and one from a global academic partner university. The course is structured in three phases:

1. Exploring the problem space, where the team gets “out there” to understand user needs [6],
2. Exploring the solution space, with rapid prototyping for learning purposes, which includes the high-risk, high-reward “dark horse prototype” [7],
3. Designing and manufacturing a final prototype, presenting, and demonstrating to an external audience at a one-day event, and concluding the year by submitting a final report covering the entire course.

The course learning objectives [8] are:

- To develop teamwork skills and manage team dynamics,
- To build skills in developing and evaluating engineering requirements,
- To develop skills in project management and planning, and
- To develop skills to produce a pre-production proof-of-concept prototype of a refined solution from a given prompt.

An additional benefit of globally dispersed teams in education is that students learn how to effectively communicate and collaborate to reach a shared goal, which tends to increase the acquisition and retention of knowledge, thinking, and self-confidence [5]. The prompt is a real problem provided by the industry partner and presented to the student team as the starting point of the exploration journey. In a previous study of the course [8], it was observed that the student teams performed better when moving dynamically between four different ways of thinking, see figure 1. The dynamic movement can be facilitated by changing the question, the solution or the solution space, the physical artifacts, prototypes, or the prototype manufacturing process [8]. Therefore, every team's exploration journey is unique, with different beginning and ending points and unique paths [8].

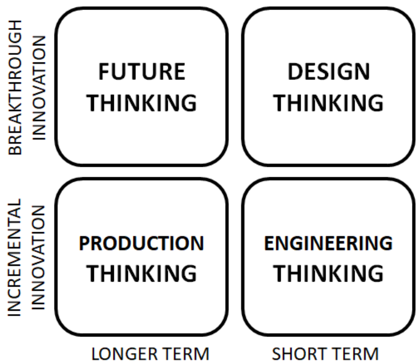

Figure 1: *Four different ways of thinking, adapted from [8]*

Besides providing context, funding, and a project prompt, the corporate partner constitutes the supporting cohort with the two academic partners and is thus invited to be involved in the student team's exploration journey. The direct values for corporate partners choosing to be involved are:

- Deep insight into a strategically interesting context, if the problem is chosen and described wisely,
- Learning from several prototypes explored by the students, and
- Documentation of the final prototype, with marketing value and potential relevance for the corporate partner's R&D function.

Another benefit for corporate partners that choose to be involved in the course is learning how to effectively collaborate in a globally dispersed innovation team when working with exploration. As an actively participating corporate partner, one also gets access to a global network of human-centered design [9] experts and enthusiasts in industry and academia.

2. Theoretical background

This study focuses on exploration work carried out by globally dispersed innovation teams, where exploration work means engineering design activities applied to an open-ended problem statement. Engineering design is a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints [1]. Furthermore, it is observed that human-designed solutions are becoming increasingly complex, partly because more robust designs are desired and partly because environmental and societal impact needs to be considered in an integrative manner [1].

2.1 Design thinking

Design Thinking is an established approach to exploration work, often referred to as a mindset and not a process [1, 9-11]. In this study, the teams have applied design thinking practices developed by Leifer, Kelley, and Winograd, among others, at Stanford University, evolving from humanistic and creative design approaches [12-13]. Design thinking aims to bring together as many different experiences and perspectives as possible, i.e., multi-disciplinary teams, which increases the potential of achieving breakthrough innovations [14]. Design Thinking aims to generate innovation from the intersection of human desirability, economic viability, and technical feasibility [14]. Its iterative nature is instrumental in solving open-ended, systemic, complex, and wicked problems [2]. The evolution of design thinking during the past 50 years has been analyzed [15], and it is suggested that the consistent core of design thinking is a cognitive process, creative practice, organizational routine, and design culture. It emphasizes finding profound needs and problems and translating them into a tangible design, creating value for people. In the course that was the context of this study, design thinking is presented, as shown in figure 2.

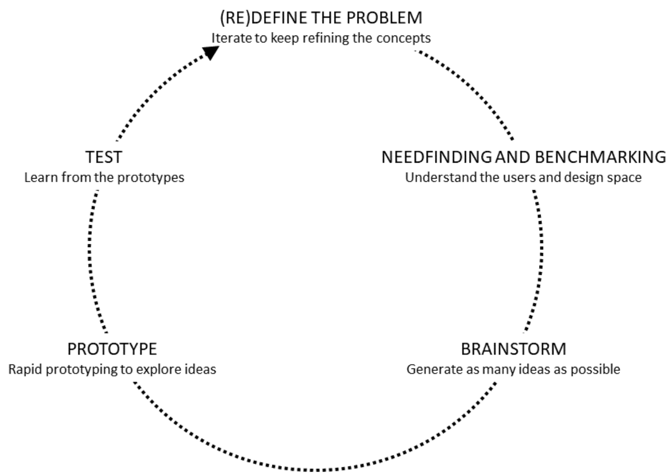

Figure 2. Design Thinking, adapted from [3]

2.2 Learning loop three

Another key concept originating from research performed on teams in the course is the triple loop learning model [16,17], which consists of three simultaneously occurring knowledge acquisition loops, see figure 3. Learning loop one is where explicit knowledge is acquired and documented, consisting of quantitative data. Learning loop two is a less formal loop where knowledge is implicitly acquired during development. If Learning loop one is centered around *what,* Learning loop two is focused around *when* and *why.* This knowledge acquisition happens in the dynamic design process and is highly dependent on external information and interactions. Knowledge acquisition is partly documented through concepts, semantics, and implicit or tacit knowledge. This knowledge acquisition can be observed when a team follows a design process and converges toward prototype building. Learning loop three involves only the team and its dynamics throughout the project. It includes *how* the team members acquire knowledge together. A supporting cohort would be most effective in guiding if it could follow the team's progress in all three learning loops without interfering with the team's learning loop three.

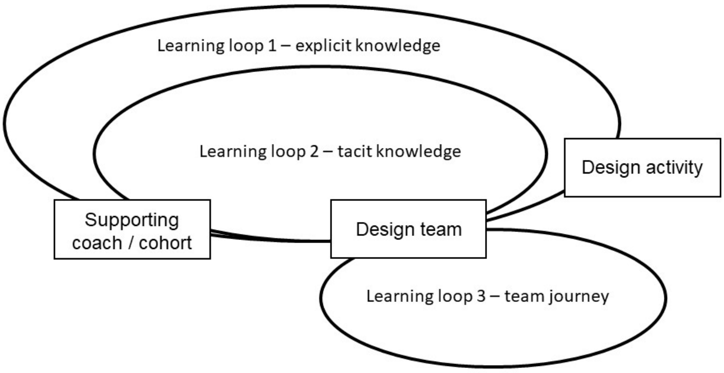

Figure 3. *Triple learning loops, adapted from [17]*

The team journey that takes place in learning loop three has been studied by scholars in this specific graduate student course for many years and contributed to the body of knowledge considering innovation teams carrying out exploration work. Some of the most relevant published work for this study is listed in table 2.

Table 2. *Research contributions with this course as a testbed*

Insights regarding innovation teams carrying out exploration work	**Reference**
A shared view of workplace activity, where all can interact through gestures, talk, subtle clues, writing, drawings, and artifacts to increase team performance	[21]
The necessity of preserving ambiguity by asking questions	[17, 22]
The benefit of building on each other's ideas, "yes, and…"	[23]
A dynamic move between convergence and divergence makes the team more successful	[24, 25, 26]
Group hedonic balance (i.e., the balance between positive and negative expressed affect in group interactions) determines the group's performance	[27]
Social sensitivity, i.e., the ability to understand the feelings and thoughts of others, is of greater importance for team performance than individual competences	[27, 28]
Trust in a team can be strengthened if team members know who has what skills	[29]
Teams can function better by actively managing their cognitive diversity, i.e., the varying individual cognitive preferences when sharing information and making decisions	[30]

One example of previous academic contributions [25] is that both the number and the type of questions being asked during a design process impact the quality of the outcome. During divergent thinking, generative design questions should be asked to create knowledge instead of discovering or constructing it from fact, and ideas are proposed as a question to promote consideration and feedback [25]. Deep reasoning questions should be asked during convergent thinking to converge on what is known [25]. The answers to converging questions are expected to hold value since the questioner expects the answering person to believe their answers to be true. Generative design questions help innovation teams expand their problem and solution spaces, while deep reasoning questions help them utilize their collective knowledge and make decisions. Another finding is the importance of prototyping as a tool for learning [26] in both convergent and divergent thinking and that prototypes can be of different kinds depending on the learning objective. If prototypes are seen as a means for learning, the number and diversity of prototypes might tell something about the team's progress. Maximum flexibility and reduced inertia by removing barriers to change allow for rapid iterations with rough prototyping, accelerating learning and expanding the solution space [17]. Furthermore, the team manages change better when there is closeness and positive emotional interactions between team members [17]. When breakthrough innovation is the goal, the team must preserve ambiguity [17], i.e., welcome new information, embrace change and allow themselves to redesign for as long as possible.

2.3 Wayfaring

The term "Wayfaring" describes the intellectual challenge of hunting for the next big idea [18], where generative design actions are comparable with a hunting mode and optimizing analytical actions are comparable with a gathering mode. The dynamic Hunter-Gatherer Model [18] pedagogically explains the two modes and their shifts. The process of Wayfaring can be visualized by plotting prototypes as they occur in time (x-axis) and have pivots represented by deviating angles (y-axis) from the previous prototype. Mapping out prototypes where no pivots have been made would then have the visual representation of a linear and horizontal development. During the hunting, the understanding of the problem is expected to increase, and consequently, the problem space would expand, similarly to the solution space where more big ideas might emerge. During the gathering, all the team's shared knowledge converges to a shared understanding, and from the solution space, a prototype is built and tested as one possible solution and as a learning tool [19].

A team on an exploration journey will most likely experience what is called the "groan zone" [20], a phase following divergence and preceding convergence, where the team needs to make all the knowledge obtained shared knowledge and, based on the shared understanding make decisions on what the next step shall be. Getting out of the groan zone requires the team to make a joint decision regarding the course of action based on all the obtained knowledge and the shared understanding to which the combination of all the knowledge led. It can be a decision regarding what problem to solve, and it can be a decision regarding what solution to prototype. In a team with a high level of trust and social connectedness [38], the groan zone should, not without struggle, take them from a group of individuals with their own viewpoints to a solid, cohesive team where all individual's viewpoints and perspectives add up into a new, collective understanding. Two recommendations for teams experiencing the groan zone can be found in the literature [20]:

1. keep team conversations focused on the objective, and
2. make sure that everyone on the team feels heard and understood.

2.4 The innovation team

The student teams in the course can be described as innovation teams, i.e., teams doing work leading to innovative outcomes [31]. Furthermore, the typical characteristics of innovation teams are suggested to be [31] that they are multi-disciplinary, have a clear shared and often ambiguous goal, are primed, or even trained for innovation work, and often have a clear process or framework to follow. The multi-disciplinarity is built on the belief that divergence in competencies prevents groupthink and strengthens the team by avoiding internal competition [31]. Based on an empirical study of large companies' innovation teams, the most important innovation enablers are suggested to be dedication, collaboration, and mindset [31]. In this case study, the multi-disciplinarity was limited as the course is a graduate course for engineering students but including a globally dispersed team led to diversity in terms of culture and education system. As part of the course's theoretical sessions, the students are informed that their team will have access to more knowledge and perspectives if it consists of T-shaped individuals [32]. The term T-shaped refers to combining deep competence in one expertise domain (the vertical part of the T) and broad general competence (the horizontal part of the T). In other words, a T-shaped individual is both a specialist and a generalist, whereas an I-shaped individual has deep domain expertise but limited collaboration abilities.

The importance of diversity in the sense of different ways of thinking, behaving, and associating in innovation teams is indisputable [33]. In the course, student team diversity has, for some years, been addressed by using personality tests [34]. Team diversity can prevent conformity [35] and groupthink [36], where either causes conformity: a) compliance to gain internal approval and avoid rejection, b) identification for being associated with liked and respected individuals, or c) internalization to be part of a group both privately and publicly. Groupthink [36] is especially common when team members have a similar background, when the group is insulated from outside opinions, and when there are no clear rules for decision-making.

An innovation team working with an open-ended, complex problem benefits from having social connectedness, which is especially difficult when the team members are not gathered in the same location [37]. Social connectedness in global design teams is largely about establishing know-who [38], defined as the interpersonal relationships that enable people to 'know who knows', to 'know who to ask', and to 'know who to trust', see table 3.

Table 3. *Know-who dimensions, adapted from [38]*

Dimension	**Is about knowing who…**
Knowledge-of-Practices	… knows how the work gets done in practice
Knowledge-of-Expertise	… knows how the work should be done, and who to ask who knows that even better
Trust-in-Expertise	… has established the relationships and credibility (social capital) in the team to be trusted

Social connectedness in a team is enhanced by team psychological safety, described as a (tacit or explicit) shared belief that the team is safe for interpersonal risk-taking [39]. An empirical study [39] found that teams with psychological safety have a shared sense of confidence that they will not embarrass, reject, or punish someone for speaking up and performing better. This confidence stems from mutual respect and trust among team members [39]. Team reflexivity is a closely related concept and is defined as an ongoing process of reflection and action, characterized by asking questions, seeking feedback, experimenting, reflecting on results, and discussing errors or unexpected outcomes of actions [40]. The level of team reflexivity describes to what extent teams reflect upon and modify their functioning [40]. In literature, a diagnostic tool can be found [41] where the following four different drivers of psychological safety together contribute to a safe environment in a team:

- Willingness to help, where everyone in the team checks in with each other and collaborate,
- Values and behaviors that foster inclusion and values diversity in the team,
- Constructive attitude to risk and failure,
- An open conversation where everyone in the team feels free to come forward with what needs to be said.

An innovation team carrying out exploration work does not have a known path to follow. Instead, they embark on a shared journey, where true collaboration, or social sensemaking, guides them to make their decisions. As the team learns and thinks together, they utilize their shared know-how and identify what to do next.

As a resource for globally distributed innovation teams, collective social capital might be neglected due to challenging goals or tight timelines. It is not intuitive for highly motivated individuals to spend time on social aspects under time pressure. As it is proven that team performance depends on it, a checklist to manage the social dimension can be helpful [42]; see table 4. The table offers a hands-on checklist which can be helpful for a supporting cohort that wants to guide an innovation team toward success.

Table 4. *Checklist for innovation teams to manage the social dimensions, adapted from [42]*

Do this:	Because:
Aim for multidisciplinarity	A mix of perspectives and knowledge domains increases innovation opportunities
Allow fair talking time per participant in meetings	Breaking the dominance of one person taking the lead and passing on information is necessary for good team spirit
Support perspective alignment	Activities that clarify and visualize distinct perspectives lead to a shared understanding that there are conflicting perspectives - which is a good starting point for problem-solving
Participants actively listen to everyone's points of view	Avoid that people prepare their own 'saying' and their turn to talk at the expense of listening to others
Provide building on each other's point of view	The knowledge domains become clear and distinct, and it becomes easier to see how integration might be possible to accomplish
Prevent judgments of others' points of view	Criticizing people for their opinions does not contribute to knowledge creation
Enable metaphorical work	Experiencing, doing, seeing, feeling, etc., to support the understanding of tacit knowledge
Support a learning process	New knowledge appears in the interface (tension) between distinct knowledge domains
Allow awareness of work progress	To avoid endless discussions and to contribute to the topic at hand

2.5 Pivot thinking

In an innovation team's exploration journey, it is beneficial to have the capability of pivot thinking. Pivot thinking [43] occurs when problem-solving thinking shifts between domain-specific heuristic systems, see table 5. A pivot is necessary when a team cannot find a successful answer to a problem using one heuristic. By asking questions that trigger a shift between heuristic thinking systems, an innovation team can, for example, regain traction if locked into one solution too early in the journey.

Table 5. *Heuristic thinking systems, adapted from [43]*

Heuristic thinking system	**Theme to move forward**	**Tool**	**Outcome**
Engineering	Analyze	Equations Analytics	Single point best answer - to a well-defined problem
Business	Optimize	Maximizing Satisficing	Single point sufficient answers - good enough solution to the problem by using the 80/20 rule
Design	Build	Empathy, Prototyping, Iteration	Multiple possible novel answers - for wicked problems with flexibility
Research	Logic	Deduction, Induction, Abduction	Internally consistent answers - for well-defined research contexts
Artistic	Feel	Qualitative	Multiple possible balanced answers - based on directional, conceptual, and experiential knowledge

3. Methodology

This paper summarizes a longitudinal study of global student teams participating in the aforementioned capstone course, where the team members are studying at either an American or a Swedish university. In the study, there were minor differences between the academic partners' course structures due to countries' different education systems; other differences were time zones, languages, and culture differences, all part and parcel of the global course learning objectives. This study was performed on student teams where the global partner was a mechanical engineering faculty in Sweden. A nimble, specialized entity emphasizes product innovation, value-driven design, model-driven design, sustainability in product development, and product-service systems design. The US engineering school students' prior knowledge is their undergraduate degrees and a mandatory course in product realization. The Swedish engineering school students are trained to mix a hands-on design thinking approach with modeling and simulation across a system-wide lifecycle perspective to include sustainability aspects and trade-offs in development work. The Swedish students perform their M.Sc. thesis projects in parallel with the course during the latter part of the course, as this is required in the Swedish higher education system. The combined final report from the capstone course and the Swedish students' M.Sc. thesis constitutes rich documentation for academic and industry partners.

A design research methodology is an approach and a set of supporting methods and guidelines to be used as a framework for doing design research. Design research combines the development of understanding and the development of support [44]. In this case study, the research methodology is inspired by Design Research Methodology, DRM [44], see figure 5. The DRM framework is a flexible yet systematic approach to structuring research, particularly helpful when the research is performed iteratively over a longer period. The methodology consists of four stages:

- Research Clarification (RC),
- Descriptive Study I (DS-I),
- Prescriptive Study (PS), and
- Descriptive Study II (DS-II)

The RC stage helps clarify the current understanding and the overall research aim, develop a research plan and provide a focus for the subsequent stages. The DS-I stage aims at increasing the understanding of design and the factors that influence its success by investigating the phenomenon of design to inform the development of support, where the term support is used to cover the possible means, aids, and measures that can be used to improve the current situation and that enable the evaluation of the core contribution of the researcher. The PS stage aims at systematically developing support, and the DS-II stage focuses on evaluating the usability and applicability of the suggested support. This study includes a review-based RC stage, focusing on understanding what characterizes a high-performing innovation team carrying out exploration work, a comprehensive DS-I stage to understand students' learning experiences and the teams' performance, and an initial PS stage.

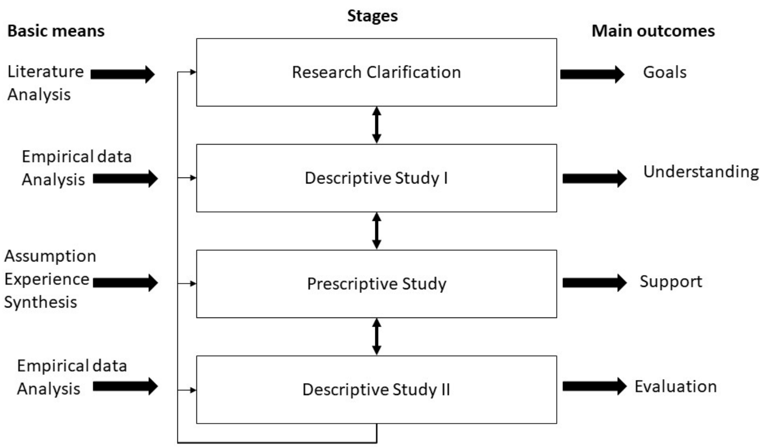

Figure 5: *Design Research Methodology, adapted from [44].*

The student team size varied from 6 to 10 students, most within a mechanical engineering master's program. Data collection, see table 6, includes semi-structured interviews performed during the year the students took the course, an online survey with alum students, 1 to 7 years after taking the course, and information exchange within the supporting cohort, consisting of the authors of this paper, two academic partners, and one industry partner. Information exchange includes journaling notes, e-mails, and two semi-structured interviews.

Based on the theoretical background presented in chapter 2, the research team approached this study with two main perspectives, one where information was collected based on the individual learning experiences, aiming at understanding the exploration journey from the viewpoint of the students, one related to team performance, aiming at understanding the exploration journey from the viewpoint of team effectiveness and outcomes. Based on this, the authors seek to understand whether a supporting cohort can guide the team without interfering with their learning loop three to help the team reach its highest potential.

Table 6: *Data collection methods*

Method	Number of individuals	Data collection period
Semi-structured interviews	16 students	2017-2020
Online survey	15 alumni students (2013-2018)	2019-2020
Information exchanges	5 supporting cohort members	2013-2020

The initial research question was: "how can we increase the likelihood of a triple wow?." Where "triple wow" is what the course instructors describe as breakthrough performance along three complementary systems solution dimensions: design, engineering, and business model [45]. The first question led to a literature review and the first round of interviews to clarify the research aim. Within the design research methodology framework, this is what is called research clarification.

Based on the research clarification, the descriptive study was designed. The first step was to understand the individual learning experiences throughout the course journey and the students' individual perceptions of the team's performance, also throughout the journey. This data was collected through one-on-one semi-structured interviews with the students. The interviews were conducted with the students as the key informants during the year they took the course. As part of the data collection, the students rated their experience against the course learning objectives and explained them with examples. The interview with current-year students was complemented with an online survey sent out to alum students, where they also rated individual experience and their view of the team's performance throughout the journey. The alums were additionally asked to describe what experience or learning in the course was most useful in their professional careers.

With a comprehensive understanding of both current year and alum students' perspectives, data from the supporting cohort was added. The cohort data consisted of journaling notes and email exchanges. The different data sources and types provided the researchers with rich data for the analysis with one defined research aim, as a sort of data triangulation [46]. The students' perception of the team performance was consecutively compared to the supporting cohort's shared view of the team performance and their opinion about the team's likelihood of reaching a "triple wow," a qualitative and subjective measure.

The data analysis was structured along the student teams' course journey throughout the school year, which made it possible to identify typical patterns and correlate individual responses regarding experience and team performance with the course structure. Instances when both the supporting cohort and students mention team struggles, or successes, were of particular interest to identify typical exploration journey patterns. Correlations between the end result and the time for final convergence, as well as the size of the problem and solution exploration spaces in terms of the number of different prototypes and pivots, were also included in the study.

4. Findings

We learned that student teams experienced remarkably similar exploration journeys by comparing data between different years. The early finding that strong social connectedness across the global team led to better team performance was reinforced by additional data. With a focus on learning loop three, where tacit knowledge is built by and within a team, we learned that the best-performing teams established social connectedness despite being globally dispersed most of the time and developed a shared mindset and psychological safety that helped them overcome obstacles and hardships. Although this learning loop "belongs" to the team, we are particularly interested in finding ways for a supporting cohort (also globally dispersed) to provide leeway for the team to "keep calm and carry on" on their ambiguous exploration journey. If a supporting cohort could follow the team's progress, both in terms of individual learning experiences and team dynamics, it might identify potential pitfalls and hiccups and take the right type of action by the right individual in the supporting cohort and only when necessary. Potentially, through subtle nudging or other guidance, the team can continue its "dance with ambiguity" [18] and increase the likelihood of a "triple wow" [45].

4.1 How to observe and support the team's social connectedness

Innovation teams that get to know each other as individuals, both task-related and socially, trust and value each other better. When social connectedness is established early, the teams perform better, deliver better results, and the individual learning experience is considered more fun and rewarding. Teams that embrace the joint learning experience on equal terms, and walk the unknown path together, utilize the differences as strengths and manage the groan zone with patience and grace. The groan zone is a challenging yet important stage for teams and results in the team's highest potential when all perspectives are utilized for creative ideation and problem-solving. We observed that teams with strong connectedness naturally utilized the whole team's skills, personalities, cognitive preferences, and perspectives to get a deep and shared understanding of the problem they wanted to solve as well as one or several solid problem-solving solutions. A supporting cohort might assist the global team in building connectedness by emphasizing its importance and sponsoring social activities. When all parts of the supporting cohort initially encourage shared work and social time (despite time zone differences), as well as the use of efficient communication technology (e.g., Slack, Google Docs, etc.), the team prioritizes it and, from their own experience, understands the value. Providing team-building exercises across the global team signals to the team that connectedness is a priority. In this study, we have observed that a good measure of the team's social connectedness is that the entire global team voluntarily engages in their own social activities without outside intervention. An opposite situation is that the global team only gets together when sponsored or when scheduled in the course.

4.2 The challenge of preserving ambiguity in a team of ambitious students

The notion of preserving ambiguity [18] is to keep alternative development paths open as long as possible. This ability is important when the purpose is breakthrough, disruptive, game-changing, and radical innovation. By rephrasing the question, reframing the context, and redefining the problem, several alternative paths toward a final solution can be taken. When the addressed problem is complex, it is particularly important to preserve ambiguity. Since most of our everyday problems are simple or merely complicated, we are better at linear thinking and step-by-step progression. Therefore, without the right guidance or coaching, teams tend to lock in on a first identified solution, which becomes the "darling we do not want to murder" [47].

It is observed that once some team members have locked in on their "darling" solution, it is difficult to get the team to reiterate; sometimes, at this point, the team divides into two sub-teams. Often, when some team members sense that they have found their "it" [48], they are unwilling to open up to any alternatives. The most effective way to avoid such a situation is to remind the team to constantly preserve ambiguity and reinforce that late final convergence tends to increase the likelihood of a triple wow.

One year during this study, the student team demonstrated that ambiguity could be preserved or regained by having the students that fell in love with one solution being the ones tasked to "murder it" and the rest of the team tasked to defend it. Not only do they mentally detach from the solution, but they also identify flaws in something that seemed perfect. The other students taking the defending role will see both pros and cons, and either the team ends up with this solution being their joint "it" and refinement can start, or they pivot. The situation we observed led to a complete pivot, and the end result was a triple wow. With a cohesive and aligned supporting cohort, these mechanisms can be taught and emphasized. The supporting cohort's role is to guide the team on its exploration journey, protect it from procedural barriers and limitations, remove unnecessary delivery stress, and facilitate recovery from cultural clashes. Innovation teams need to not only manage the uncertainty but also embrace change as a companion while they learn to master the art of dancing with ambiguity.

4.3 Formulating a prompt that enables exploration

Already when the prompt is first presented to the team, the supporting cohort should reinforce the view of change as a companion and that their exploration journey requires preserved ambiguity. Therefore, the prompt formulation needs to be open enough to allow for exploration in both the problem and the solution space and still relevant to the company's strategy, as the time and money investment as a corporate partner is not negligible. New opportunities can come from a widened context, where the team zooms out from the existing situation or explores opportunities further into the future. The initial problem described in the prompt might not be the problem that needs to be solved but a good enough starting point for framing the contextual space to explore. Providing the prompt is a task for the corporate sponsor but learning from this multi-year study that it gets better when formulated together with both academic partners. A well-formulated prompt involving several corporate colleagues and both academic partners pays off already during the fall semester when the students might get frustrated and ask for clarifications or directions or when the students need a small nudge to get out of their comfort zone, i.e., campus and conduct proper need finding. With a well-coordinated supporting cohort understanding the meaning and purpose of the prompt, it is easier to demonstrate to the team that they can trust the process.

In table 7, some prompts presented to the student teams during the years 2014 to 2020 are listed. The most successful prompts have the following four characteristics in common:

1. Relate to a business segment, an industry, or a context that the corporate considers interesting in its long-term strategy

2. Include both corporate background and an initial problem statement

3. Asks more questions than give answers. The questions are open-ended and intended to provide direction for the initial needfinding

4. Include contact information for several corporate representatives and encourages the team to reach out anytime

Table 7. *Some of the corporate's prompts initially presented to the student teams*

Enhancing partnership between humans and vehicles in the connected society
The pains of today and the concerns of tomorrow in the construction industry
How will autonomous machines cooperate with human coworkers?
The future of waste and recycling - turning waste into value
A construction industry without raw material - urban mining

Once the corporate liaisons have presented the prompt; they are most helpful to the student team by staying out of the team's work for most of the fall semester. The corporate liaisons can provide contacts and share relevant reading material; however, sharing knowledge this early is too limiting for the team. With corporate expertise staying out of the conversation, the students can explore the prompt with what Japanese Zen Buddhists call a beginner's mind and build their understanding of the problem space, users' needs, and contextual limitations, which will invariably differ from the industry's conventional wisdom. Students are unaware of this and might reach out to obtain information and guidance, sometimes impatiently wanting an answer to the question, "what do you want us to do?". It can be tempting for the corporate liaison to fall into an expert role and tell the team what they should look for or aim for, but it is necessary to refrain from that so that the team can "dance with ambiguity."

The prompt can function as an efficient tool for the supporting cohort to identify when to interfere, for example, when someone in the team spots a risk for premature convergence. It was observed that only suggesting that the team revisit the original prompt helped to open up and preserve ambiguity, especially in the teams with strong social connectedness. The two types of situations where the supporting cohort has needed to interfere are:

- Too narrow need finding - the team is locking in on one specific user and identifies a need that they "fall in love with," no further problem exploration is done, and the direction typically misses the long-term transformative ambitions articulated in the prompt formulation,

- Too limited benchmarking - the team finds their favorite user, points out one problem, and the team goes ahead solving just that, missing either that there are existing solutions on the market or that the solution they come up with gets endorsed by that one targeted user is not addressing an industry-wide ambiguous problem.

The team can avoid these situations by expanding the problem and/or the solution space. The supporting cohort can guide in this by providing new perspectives and new users, encouraging the team to explore a dark horse prototype, and in other ways, helping the team to zoom out and question ingrained truths Teams that iterate back sometimes end up in the same direction but with more knowledge and confidence. They might make a slight change of direction or pivot dramatically. The supporting cohort can assist by reminding the team to trust the process and always reinforcing the importance of preserving ambiguity. A team of young, ambitious students might see all the missions as tasks that need to be executed and feel that reflecting, revisiting, and reiterating are a waste of time. However, they learn important skills for exploration work and are better prepared for their careers.

4.4 The supporting cohort needs to be a team

Radical innovation requires that the team is provided space, organizational, institutional, and procedural freedom, as well as organizational support to break through the boundaries of established knowledge [17]. By checking in with the team regularly, listening more than talking, and accessing the team's chat channel and documentation repository, the supporting cohort can have a light touch of involvement and intervene only when needed. The individuals closest to the team can provide timely information or personal introductions that might be helpful for the team exactly when they need it. When the supporting cohort can function as a team, the need for corrective actions, nudging, or intervention, can be observed by anyone in the team, and the team can jointly decide how and whom to manage the situation. The study observed that the corrective action is effective when teams receive coordinated guidance from the supporting cohort. In contrast, less aligned supporting cohorts have confused or caused frustration or disconnect in the global team.

In the supporting cohort, the individuals can remind each other about the boundary conditions – such as the prompt, the context, the syllabus, and the team composition. Corporate liaisons support with context, connections, and domain expertise. Academic partners support educational content, including engineering design, design thinking, rapid prototyping to accelerate learning, and the mindset of constant redesign. While the connection with the student team throughout the year is important, communication with peers in the supporting cohort impacts the learning experience and team performance significantly. For a corporate to get involved in a graduate student course can be a very cost- and time-efficient way of gaining knowledge, but only if the corporate liaisons get involved with both students and academic partners. The mutual interest to learn from each other and contribute to each other's success generates a shared long-term goal, which yields short-term wins in developing skills and research contributions and long-term wins that impact the strategies and directions of the different institutions.

4.5 The course from the students' perspectives

13 alum students that had taken the course from 2013 to 2018, pursuing their professional careers for over two years, rated in a survey their individual learning experience on a scale from 1 to 7. They also responded to a free-text question about what skills they learned in the course that they use professionally today.

Table 8 lists the average rating by students regarding the four learning objectives, where the maximum deviation from the average was one unit, +1 or -1.

Table 8. *Average rating by students*

Learning objective (individual)	**Average rating by students (1-6)**
Teamwork/team dynamics	6
Engineering requirements	5
Project management	6
Refined POC from prompt	6

Below are free text responses regarding what skills from the course alum students use professionally. One common theme is the global team collaboration experience.

"To make collaboration work in a highly diverse team, remotely and with challenging time zone differences. Definitely a good skill to have now during the pandemic."

"My collaboration skills with different cultures, my project management skills, as well as being agile and flexible in my way of working."

It complicates the work for both students and the supporting cohort that the teams are globally dispersed, but former students see that as a valuable learning experience. Experience in asynchronous collaboration and effective communication through different sharing and chatting tools is beneficial for many professional careers. Some teams even experienced how time zone differences can be considered an additional asset; taking turns in the design work can accelerate progress so that the working hours per day are almost doubled. A competence that is not commonly seen in the industry.

Another common theme is the experience of the exploration journey, where knowledge is gained through prototyping, and the perfect solution is not the goal but a satisficing one.

“A lot of times, I felt like I did not have enough time to get things done. While this meant that I was not able to refine and complete all my deliverables 100%, it did force me to develop a style of working that reduces wasted time. Now that I work in the industry, I see that not all of my colleagues have developed this skill. I have found that engineering is mostly about finding "good enough" solutions that are not perfect - but that can be executed on time and budget. This experience taught me to prioritize my time and get comfortable with the "good enough" solution instead of spending endless hours optimizing.”

“I still use the concept of a "critical function prototype" regularly. And more generally, the overall strategies for tackling open-ended design challenges have been extremely useful.”

“Prototyping to answer a question. Prototyping to define design requirements. Design space exploration tools and the design process were very useful during my Ph.D. work.”

“The most important skills that I learned and use today were: (1) Need finding - thinking about the problem space and taking time to frame and approach the issues at hand before diving into a solution (2) Resilience - being willing to dive into very uncomfortable ambiguity and feel crushing defeat, and still fight our way back and re-commit to delivering an impactful project result.”

Those responses provide students’ reflections on the learning journey they experienced in the course and how “real” that experience is for professional life. This reinforces the idea behind the course structure and the value of a supporting cohort that can guide the team on its journey.

Two other responses we would like to highlight as key benefits of this type of learning experience are:

“It is easier to get important learnings in an early project phase and to keep notes. They could be very helpful when you least expect it, later in a project.”

“Working in a team, breaking down a problem into manageable pieces, building my confidence in my capabilities, mechanical design, manufacturing (learning how to build).”

Students having these insights after the course can enter the job market with skills to explore and solve for breakthrough innovations that might become increasingly important during uncertain times with an urgent need for sustainable development in an unpredictable geopolitical landscape driven by the recent global pandemic, global climate change, new demographic conditions, and migration patterns. Our data shows that students find the course experience relevant to their professional careers. Furthermore, the data shows that students experience that the learning objectives are met. The brief time spent on each mission during the course is not surprisingly seen as frustrating, and some missions are considered to be a bit artificial, as the team only has time available to make one attempt. Still, with the limited time available, the course seems to be an appropriately balanced learning experience.

4.6 Proposed tools for the supporting cohort

There are ways for a globally dispersed supporting cohort of academic and industry partners to calibrate among themselves and guide an innovation team carrying out exploration work without interfering with team dynamics and performance. The ultimate goal that innovation teams can carry out exploration work can be guided to avoid unnecessary pitfalls or mistakes, both from the perspective of their work outcomes and how they function as a team. Tools that a supporting cohort could be helped by should not require additional efforts by the team and should not require changes to the course syllabus or curricula. The supporting cohort should find the tools easy to apply and share. In this study, we identified two potential tools for supporting cohorts. The main purpose of the tools is to a) identify challenges related to social connectedness and team dynamics and b) help the team to preserve ambiguity. The tools we suggest would not require interference with the team's learning loop three but require that the supporting cohort is engaged with the team and can walk closely by them on their unique path. One tool addresses the team members' emotions, and the other addresses the prototype's progress. The first tool is inspired by customer journey mapping, described as a visual depiction of the sequence of events through which customers may interact with a service organization during an entire purchase process [49]. The events are called touchpoints and are accompanied by emotional indicators. The journey map can be applied to higher education institutions, where students are seen as "customers" and academic institutions are seen as service organizations [50]. In our study, the journey would be the academic course journey, and in industry practice, the journey would be the explorative project journey. The first time the journey map was introduced in our study was to structure and correlate observations and interviews. In analyzing data, the research team correlated individual learning experiences, team members' perceptions of the team performance, and team performance according to the supporting cohort. From the first set of interviews, a "typical" pattern was identified, providing a structure for following data collection, ending up being structured in eight chronological phases (events), see table 9.

Table 9. *The team journey, structured in eight chronological phases*

Phase / milestone	**The experience of…**
A: Corporate project launch with the global team	… the global kickoff when project prompt is presented to the global team
B: Problem exploration	… expansively explore the problem space
C: Making fall presentation and report	… synthesizing the problem exploration journey, converging on a prototype, presenting it, and delivering a fall report
D: Solution exploration	… exploring the solution space with several prototypes
E: Making final convergence	… the groan zone leading to the decision about what to build
F: Building the final prototype	… designing and manufacturing the final prototype and preparing the final presentation
G: Presenting and demonstrating at EXPE	… presenting and demonstrating for a large external audience
H: Concluding the year with a final report	… concluding the year with a final report, and for the Swedish students, the M.Sc. thesis

Figure 6 visualizes the pattern from all respondents' responses. The semi-structured interviews opened the questions to explore the connection between individual learning experience, team dynamics, and team performance. Subsequently, the survey questions were:

- During or between what phases/milestones did you experience that you as a team struggled with the most (negative experience)?

- During or between what phases/milestones did you experience that you as a team performed the best (positive experience)?

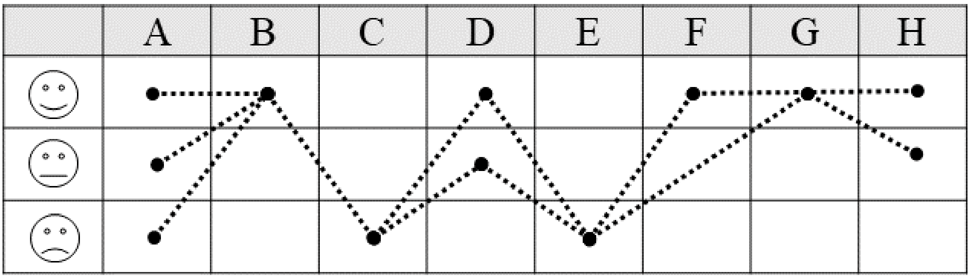

Figure 6. *Team journey map, based on student responses in interviews and the survey*

Table 10 summarizes the comprehensive analysis of data from interviews and the survey.

Table 10. *Summary of the analysis of student data*

Phase / milestone	**Analysis**	**Pattern**
A	A negative experience for some due to the open prompt, causing frustration for ambitious students that wanted to achieve impressive results rapidly. A positive experience for some due to the open prompt, which is seen as an opportunity to create whatever they wanted. A neutral experience for some, reserving judgment as this was just the beginning.	No
B	A positive experience for most respondents. Conducting need finding and benchmarking "in the wild", away from the comfort of the campus, is a rewarding and divergent learning experience, both educational for the individual and a team-building experience as shared understanding is obtained.	Yes. Positive.
C	A negative experience for most respondents. Stress and disappointment as a third of the course are concluded, and students feel that they are nowhere near what they had hoped for. The value of a rich and informative fall report is not understood at this time. Several alumni students mention the CEP (critical experience prototype) and the CFP (critical functional prototype) as key learnings for their professional careers, but during the experience this is not yet understood.	Yes. Negative.
D	According to most respondents, rapid prototyping, testing, and iteration are positive experiences. During this phase, most of the respondents feel like they are two separate teams due to educational system differences. Teams with solid social connectedness stay in touch and share their learnings. The few respondents rating this as a neutral experience explain it with a too high pace of prototype building and testing and too little time for reflecting and learning.	Yes. Positive or neutral.
E	Not one single respondent rated the final convergence experience as positive. As expected from the groan zone. One observation is that teams with solid social connectedness shifted from this negative experience to the next phase, a positive experience, quicker. In a less high-performing team, the change is either not as dramatic (negative to neutral), or the shift to positive is slower. A good team embraces the pains, struggles, and hard joint work and comes out from the groan zone feeling confident, cohesive, and excited to execute their shared "IT."	Yes. Negative.

F	Demanding, challenging, and stressful, with many roadblocks and hardships to overcome. But a phase where progress is tangible, and frustrations can be managed by working harder. Interviewees tell stories about how well the team collaborated between time zones and how seamlessly they dealt with unexpected challenges such as design mistakes or lack of material. Once the team has decided what to demonstrate at EXPE, most respondents consider it a positive experience. Some respond that it is a neutral experience, as they cannot make their prototype or presentation perfect due to time pressure.	Yes. Positive or neutral.
G	An intense and hectic one day experience, considered positive by all respondents. This event concludes the team journey, and they get to demonstrate their prototype and knowledge they have obtained and celebrate. Besides being proud, several mentions a sense of relief. The unique learning experience is over, and respondents express both gratitude and slight exhaustion.	Yes. Positive.
H	A positive or a neutral experience. Besides making the final report to the global team, the Swedish students finalize their M.Sc. theses. The final report is a quite straightforward delivery, associated with a reasonable workload by all interviewees.	Yes. Positive or neutral.

The intent of the dark horse prototype, DHP (dark horse is the outside bet in horse racing), is to challenge the team to seek solutions in new audacious areas that might not be explored in a rational development effort [7]. A successful DHP is technically well-executed and user-tested to push the design space boundary [19] and effectively used at the right time; the DHP can help a team to explore a pivot away from a too-narrow, longitudinal development. This study observed that the DHP timing might be good for educational purposes but not the most effective in industrial contexts. In the course, the DHP is introduced to the team at the beginning of the winter semester, right when they start to explore the solution space with the argument that the team should be aware of the tool and use it themselves when they feel it is necessary but is most likely more impactful if introduced after the team has built and tested a few prototypes, to help the team expand their solution space, i.e., preserve ambiguity. This might not be important for the educational setting, but in the industrial context, the timing of interventions might influence resources. In figure 7, we have sketched out a first rough prototype of a tool for a supporting cohort. Sharing this as the joint calibration across the cohort might provide information that helps the team to nudge, coach, and intervene in a coordinated, subtle, proactive, and effective manner. A basic schematic showing "typical" patterns could serve as a template against which the supporting cohort can share observations and reflective notes. The supporting cohort should remain external to the team; therefore, they could either have a light touch of regular check on the individual's experience during their journey, as simple as a happy, sad, or neutral face or assess the emotional state of the students without asking for their input, which would require open and transparent sharing from the team throughout the journey.

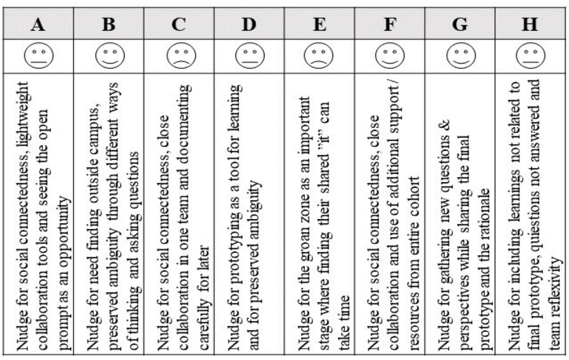

Figure 7. *A sketch of a team journey map template to be used by the supporting cohort.*

The hunter-gatherer map inspires the second tool for the supporting cohort as a visualization of the team's learning journey through prototypes, or "Wayfaring" [18]. This tool can help the supporting cohort guide the team in preserving ambiguity. The visualization should not be seen as a static map but rather as a dynamic visualization of the team's moves between different prototypes during their journey. An unpredictable model that allows for awareness, observation, and real-time intervention. Departing from an open, ambiguous corporate prompt, the team starts by articulating their first solution vision and then builds and tests their first prototype to begin exploring the unknown. With every learning iteration, new insights lead to a revised vision for a solution and the ongoing hunt as the divergent Wayfaring continues. The team repeats this cycle of abduction/prototyping, testing, and learning until they find their big idea, which they feel is most promising, which is by Savoia [48] named their "IT" – or they run out of time.

Figure 8 shows an example of a Hunter-Gatherer map for the 2019-2020 team [51], created by co-author Christian Johansson Askling as a test. The first solution vision was recycling assistance, driving a first experience prototype into a rotation of trash containers. Based on this and subsequent learning through the journey, the vision evolution and corresponding prototypes are visualized. Inspired by the shortage of personal protective equipment at the beginning of the Coronavirus pandemic, they pivoted towards the vision of recycling single-use protective gloves. The pivot is represented by a sharp angle deviation in the figure. Without a pivot, that map would show a continuous linear journey. The example above is an example of preserved ambiguity with late final convergence. Leading to a triple wow in the course and ranked within the top 20 of 1800+ entries in the James Dyson Award competition. This hunter-gatherer map was part of the analysis of that team's journey retrospectively and held a promise as a model for the supporting cohort's facilitation of the team's internal learning process [26]. With this, the cohort can share a back-office dialogue and decide when and what feedback the team needs. To pivot requires a significant amount of courage for a team, and if that seems necessary, the cohort can provide a coordinated effort to give them the confidence to "kill their darlings." Visualizing the project from an overall perspective through the journey allows the cohort to align and provide timely support for tough situations and decisions.

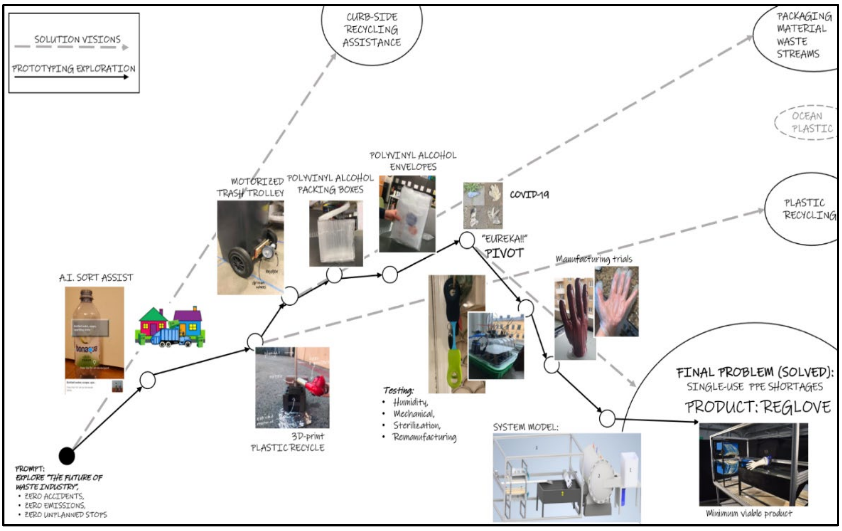

Figure 8. *An example of a Hunter-Gatherer map for a student team by Johansson Askling [51]*

The Hunter-Gatherer model demonstrates how the journey works with the *what* perspective. Furthermore, how both curiosity and ambiguity are managed and preferably preserved. During Wayfaring, the team increases understanding of the context and expands problem and solution space. A hunter-gatherer map shared across the supporting cohort might help a supporting cohort to be more aware of the status of the team and more aligned. For example, a team moving linearly from one prototype to the next within a narrow solution space might prove to the supporting cohort that intervening is necessary.

5. Discussion

In this study, we explore if a supporting cohort in an educational setting can guide an innovation team to do explorative work to maximize learning experience and performance. For education, this is the only purpose of the suggested tools, but in an industrial context, such tools might also help bridge the exploration and exploitation sides of the business [52]. It is common that the exploration work is tolerated by business leaders but not considered to be of strategic importance. A breakthrough opportunity might be missed, and a promising conceptual solution might be poorly explored when understanding and transparency from exploration work are lacking. With a supporting cohort representing different organizational functions and using suggested tools, innovation teams in large organizations might become more successful and better integrated with the larger organization. A supporting cohort consisting of individuals that understand the difference and equal importance of exploring and exploiting, yet with different skills and motivations, can support the team and guide them to reach their full potential. The awareness that explorative innovation work generates insights about the context and user needs that can generate several solutions concerning several time horizons can bring stability and strategic alignment to an ambidextrous organization [53]. Innovation teams can be coached on their exploration journeys, like how athletic sports teams are being coached. The supporting cohort must agree not only on which sport to play and what the corresponding rules are in that sport but also on how the team should play the game based on the challenge at hand and the team composition. Just like a sports coach, a person in a supporting cohort is there to help the team work together towards achieving their full potential, which rarely happens by "showing how it should be done."

A team journey map can help a supporting cohort to be more effective in guiding an innovation team. A hunter-gatherer map can help the supporting cohort understand whether the team is preserving ambiguity and whether they have expanded the problem and solution space sufficiently. Using the two supporting cohort tools can increase the likelihood of a triple wow in the educational context. In a corporate context, it can both boost the innovation team's performance and increase the understanding and acceptance in the surrounding organization. By capturing both the team dynamics and the team's exploration performance, the supporting cohort might be able to increase the likelihood of success. By adding those two tools, exploration work in education and practice might be better understood and supported, which would be interesting and relevant to future research.

6. Conclusions

From this study, we conclude that work carried out by an innovation team on its divergent and convergent exploration journey can be guided and performed both transparently and systematically, vastly different from traditional and linear product development processes but still possible to document, quality assure, and learn from. The likelihood of success for an innovation team performing exploration work can be increased by a supporting cohort's coordinated guidance focusing on social connectedness and preserved ambiguity. In this study, we have contributed with an additional understanding of factors that impact the performance of innovation engineering teams. We suggest two lightweight tools for supporting cohorts when collectively guiding a globally dispersed team without adding a significant workload. The tools are in this study considered to have potential but have not been further explored. Future work would be to follow a supporting cohort applying one or both tools and analyze the applicability and effectiveness of the tools for the supporting cohort and the impact on the team. The hunter-gatherer map requires that the prototypes be visually represented, which might limit the tool's usefulness to projects where tangible learning prototypes are produced. It might be possible to utilize more sophisticated digital tools to automatically capture and follow the progress. This could aid a supporting cohort in noticing unwanted situations and acting quickly.

The relevance to education and industrial practice is limited to innovation teams carrying out exploration work, where breakthrough, radical or game-changing innovation is the ultimate goal. The skills that future engineers will need to master include the traditional knowledge domains and the ability to solve systemic, complex, and wicked problems. Academy and industry need to adopt engineering skills for explorative innovation work, maybe better described as innovation engineering [54], as strategically important core competencies with the traditional. Because of exploration's non-intuitive, non-linear, unpredictable, and ambiguous nature, guiding tools might help continuous and strategically aligned support.

Declaration of interest
The authors declare that there is no conflict of interest.

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Paper G

Lost in translation between exploration and exploitation:

From selling products to solving problems in large manufacturing incumbents

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Abstract

This paper summarizes a two-step study consisting of a multiple case study within one large manufacturing incumbent followed by a survey-based study with respondents from similar companies. The study aimed at understanding the challenges within these companies as they extend their scope from products to Product-Service Systems (PSS). Trends of adopting digital technologies in this shift necessitate changes in processes, decision-making, and mindsets, making the ability to explore new opportunities while exploiting existing ones, i.e., organizational ambidexterity, critical to current and future successes. We identified a gap between exploration and exploitation work streams within these companies, leading to promising conceptual PSS solutions being "lost in translation" between successful exploration project outcomes and exploitation project input. Our method to build an understanding of this problem included a multiple case study within one large manufacturing corporation and a survey-based study where we gathered insights from leaders with exploration-oriented roles within other large manufacturing incumbent organizations. Our findings suggest that the identified gap is common across different industries and manufacturing corporations, and there are examples of successfully bridging that gap. This study contributes to understanding the gap between exploration and exploitation. It proposes approaches to help bridge this gap, enabling a corporate-wide shift from a product-centric to a PSS-oriented organization. The research findings also have implications for companies adopting digital technologies to shift their businesses to integrated solutions. By recognizing and addressing the gap between exploration and exploitation, companies can improve their ability to develop and validate innovative PSS solutions together with customers, leading to successful revenue generation.

Keywords: Organizational ambidexterity, intentional PSS design, bridging exploration and exploitation, the buffer role

Introduction

Traditional business models are being challenged and outcompeted by new ways of providing value to customers, as demonstrated by actors like Uber, Amazon, Netflix, Tesla, and SpaceX. New forms of partnerships are enabling integrated customer solutions providing convenience and predictability to customers, who can opt to pay per use, per performance, or per result instead of investing in capital-intensive assets with optional financial or aftermarket services (Tukker & Tischner, 2006; Borg et al., 2020). However, shifting from a product-centric to an integrated product-service-system (PSS) paradigm necessitates new ways of working, mindsets, and partnerships with deeper integration and interdependency than traditional supplier-customer relationships (Galera-Zarco & Campos, 2021; Vargas et al., 2022; Wallin Nylander et al., 2015). Large manufacturing incumbents that have made this transition describe company-wide transformations impacting business models, competencies, partnerships, organizational structures and processes, mindsets, and cultures (O'Reilly & Tushman, 2011; Smith, 2013; Wallin Nylander et al., 2013; Onufrey & Bergek, 2020). According to Kennedy (2003), large manufacturing incumbents, which are dominant firms that design, develop, manufacture, sell, and service products, maintain competitiveness mainly through incremental product improvements and an optimal balance between cost, quality, performance, and features. These incumbents operate in repeatable industry life-cycle patterns (Klepper, 1997), enabling them to identify new market entrants and partnerships early on and respond accordingly. Linear product development processes, involving a systematic sequence of stages and gates that integrate significant manufacturing constraints and considerations, provide stability and predictability for efficient and continuous delivery of incremental innovation and quality product updates (Isaksson et al., 2009).

This predictability has allowed large incumbents to optimize their processes and investments, remaining competitive and relevant while building on their past entrepreneurial success (Collins, 2002). This game changes as technological advancements and global interconnectivity among people and things cause a new rapid, complex, and nonlinear change pattern that is marked by the following three dimensions (Chima & Gutman, 2020):

- It is perpetual — occurring all the time in an ongoing way,
- It is pervasive — unfolding in multiple areas of life at once,
- It is exponential — accelerating at an increasingly rapid rate.

Organizational ambidexterity and strategic alignment are critical for large companies seeking to adapt to change and innovate (O'Reilly & Tushman, 2016). O'Reilly and Binns (2019) propose that large incumbents can overcome the odds of disruption by mastering ideation, incubation, and scaling of their new innovative solutions, with scaling being the least established in large firms. There are numerous examples of product makers shifting their focus from providing product features to delivering value, or PSS solutions. This shift impacts the company's identity, going from an original equipment manufacturer to an entrepreneurial enterprise, potentially inspired by Amazon, the world's largest online retailer and a pioneer in cloud computing (Lisdorf, 2021) with an approach to start with customer obsession and work backward (Bryar & Carr, 2021) to innovate and grow continuously.

This paper presents a study performed in two separate steps, the first being a multiple case study where the gap between exploration and exploitation work streams is causing that conceptual PSS solutions are being "lost in translation" between successful exploration outcome and exploitation input, leading to those radical innovations which could be disruptive competitive advantages never reach a revenue-generating stage. The initial motivation for conducting the multiple case study was that the main author witnessed how several promising PSS solutions did not progress towards market launch, despite being proven both technologically feasible and customer desirable. Observations showed that the reason for this flaw was an unsuccessful handover from exploration to exploitation within the company. The multiple case study was made within one large manufacturing corporation. The other step of the study focused on investigating whether the findings in the multiple case study are shared across industries to identify additional roadblocks and enablers for PSS solutions to progress within product-centric organizations and to investigate how PSS solutions can aid shifting the mindset and corporate identity. The structure of the paper is that the two steps in the study are described distinctly separated but otherwise combined.

Theoretical background

Product-Service Systems, PSS, is a commonly accepted term in the industry, referring to the integration of product and service offerings (Tukker & Tischner, 2006). Many companies have successfully shifted their mindsets and business models from traditional product offerings to integrated PSS solutions. Examples of large manufacturing incumbents that have accomplished this shift include GKN Aerospace, Hewlett Packard, and Sandvik Coromant. GKN Aerospace (GKN Aerospace, 2023) provides customers with a range of advanced systems, components, and technologies for aircraft propulsion and aerostructures, along with engineering services and support. Hewlett Packard (Hewlett Packard Enterprise, 2023) offers information management solutions, such as software and hardware products, services, and consulting, to help customers effectively manage their digital information. Sandvik Coromant (Sandvik Coromant, 2023) offers cutting tools, tooling systems, and customized machining solutions to help customers improve their machining productivity and reduce costs. The core constituents of PSS solution design, or *Functional Product Development* (Isaksson et al., 2009) are:

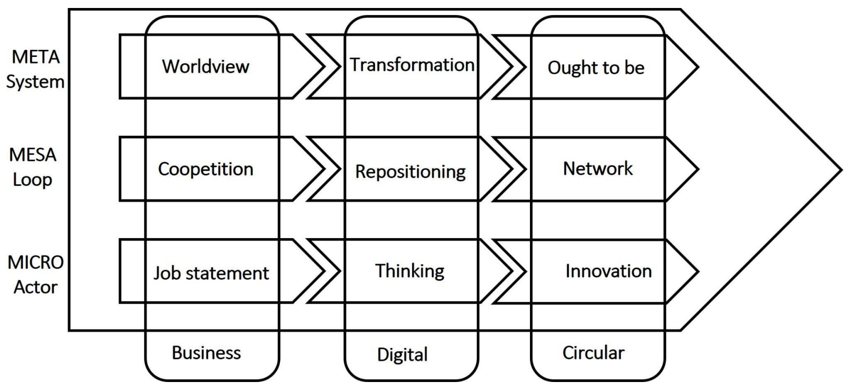
- Focus on finding a solution to customer needs,
- A high degree of customer involvement during development (means more than being customer-centric),
- Networked, global development with customers, partners, and suppliers,
- Modeling and simulation of all aspects of PSS in early phases.

The emergence of integrated solutions that combine physical products with digital service components has become standard in consumer electronics, passenger cars, trucks, and other industrial solutions. A new generation of PSS solutions is emerging in response to Industry 4.0, digital transformation, and global sustainability and circular economy trends. This new approach moves beyond the traditional view of PSS solutions as physical artifacts bundled with add-on services to more sophisticated solutions where interdependent physical and digital components deliver value to the customer. Furthermore, as data is collected from usage, PSS solutions can be continuously optimized and enhanced, leading to improved service and repair, accelerated innovation cycles, extended, intensified customer relations, and additional revenue streams

(Schulz et al., 2021). A PSS solution can be represented by a digital simulation model that can zoom in on specific hardware or software functions and zoom out to the systemic level in a complex, dynamic system. As PSS solutions become more complex, new types of value constellations and business partnerships are emerging, with PSS solutions comprising technical, social, and digital designs. When creating PSS solutions, three context levels should be considered: micro, mesa, and meta-levels (see Figure 1). The micro level focuses on an individual actor's job, task, or activity. In contrast, the mesa level addresses an operational level where several actors' tasks or activities are part of an interdependent process. Finally, the meta-level addresses the systemic level, considering the complex system of society globally. This way of thinking enables a systemic consideration even in the early stages of conceptual design (Lugnet et al., 2020) and early simulation models (Jones et al., 2019).

Designing PSS solutions with a systemic and evolutionary perspective requires considering what the future system level might look like and what that means for the operational and job levels. This approach takes into account technological advancements and societal developments.

Figure 1. *An updated discourse on PSS, adapted from Lugnet et al. (2020).*



Product-Service System (PSS) design is a way to create solutions that meet the needs of users and customers from a combined product and service perspective. However, in this paper we are inspired by Lugnet et al. (2020) and propose an intentional PSS design approach that goes beyond addressing current customer needs and market conditions. This holistic and integrative design process includes a vision for a desired future state from the start, allowing for an evolving solution that incorporates various combinations of products and services over time, including future scenarios with emerging technologies and practices. Compared to how PSS solutions are typically created in industry, where services are added to existing products, the intentional PSS design approach considers a systemic level and prepares for both current and future needs and opportunities in an evolutionary manner. This approach results in customer-satisfying solutions today and prepares for evolutionary updates that satisfy future customer needs and market requirements. Digital technology enables access to data, models, simulations, and visualization for decision-making based on historical, real-time, and synthetic data. For example, Building-Information-Modeling (Cassini, 2022) is used in large infrastructure projects for projecting, bidding, and billing. This approach allows for the integration of physical and digital representations of the solution, resulting in a real-time digital twin. A PSS digital twin can help with decision-making, collaboration, and knowledge sharing, and synthetic data can be used to create a conceptual digital twin, even without having the representative data, to identify data collection and sensor needs (Almirall et al., 2022). By developing a digital twin and visualizing data, designers can improve both collaboration and integrated solutions (Wall et al., 2020). To achieve a climate-resilient circular economy, designers can apply principles such as careful resource utilization, development of long-lasting and recyclable materials, and design for disassembly for reuse, among others, in alignment with the intended circular economy concept (Korhonen et al., 2017; Jonker et al., 2017). With an intentional PSS design approach, designers can prepare for an anticipated future that is climate-resilient and circular, while still addressing current customer needs and market conditions. This requires an evolutionary design approach that incorporates updated software and hardware based on new learning and technological possibilities.

The study presented in this paper aims to elucidate the gap, or disconnect, between exploration and exploitation, leading to that promising PPS solutions get “lost in translation” and with that also both concept and context understanding. As an innovation team explores problem- and solution spaces, iterates, and sometimes even pivots, it builds knowledge far beyond what is usually documented. This knowledge building can be understood by using the term knowledge maturity (Johansson et al., 2011) and include:

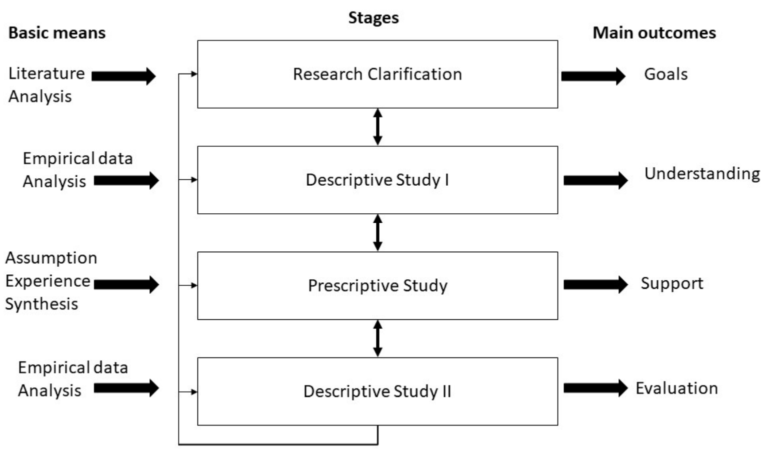
- Boundary negotiation - determining the boundaries for the shared knowledge base to know what we know collectively,
- Tacit knowledge sharing - assessing the level of expertise in the team and knowing where to find people with knowledge, skills, and experience,
- Visualization - creating a representation of where knowledge is sufficient versus where additional knowledge needs to be acquired,
- Traceability - shared understanding of how different components of a conceptual PSS solution contribute to the whole,
- Prioritization - making it possible for the team to create a shared view on the most critical knowledge building to proceed versus what can be put aside for later,
- Pragmatic decision making - the team can understand what decisions need to be made based on preliminary evidence versus what decisions require specific additional actions to retrieve information.

Methods and aim

This article discusses a multiple case study of large manufacturing incumbents, which are market-leading and manufacturing multinational companies. These companies have built long-term sustained competitiveness by providing premium products to loyal customers. Some manufacturing incumbents have shifted from product-centric to service-oriented operating models, from selling products to becoming PSS solution providers.

The Design Research Methodology (DRM) framework (Blessing & Chakrabarti, 2009), see Figure 2, was selected for its ability to structure data iteratively. In this study, we applied the framework's two steps, descriptive study I and preliminary prescriptive study, to gain a deeper understanding of the problem and identify potential solutions. During the descriptive study I phase, we conducted a thorough investigation of the problem space, collecting and analyzing data from a variety of sources such as project documentation, journaling notes by the main author, semi-structured interviews with stakeholders, and existing literature. This step allowed us to identify the key roadblocks and enablers associated with the problem and gain a deeper understanding of the problem, which was present in multiple cases within one large manufacturing corporation and recognized by respondents representing other large manufacturing companies. Next, we moved into the preliminary prescriptive study phase, where we developed potential solutions to address the problem. This involved developing conceptual approaches to mitigate and overcome the problems and testing hypotheses on stakeholders. Through this process, we identified promising approaches to be further tested and evaluated, which are not covered in the study presented in this paper. Throughout both phases, we used an iterative approach, continuously refining our understanding of the problem and potential solutions as we progressed. This allowed us to identify and address gaps in our knowledge and test and refine our solutions continuously, all with the aim to help companies avoid lost business opportunities as well as wasted time and effort.

Figure 2. *Design Research Methodology, DRM, adapted from Blessing & Chakrabarti (2009).*



The aim was to explore why promising and conceptually proven PSS solutions fail to reach the market, despite a company strategy supporting the shift from product-centric to PSS solution-oriented, a clear market pull, and partners' willingness to share risks. By identifying roadblocks

and enablers in multiple cases, this research can provide insight into what to avoid, what to reinforce, and how to facilitate PSS solution progress and company identity shift.
The following two research questions were formulated:

RQ1: Why do promising PSS solutions get stuck in the large manufacturing incumbent's development process, despite an intent to shift from product-centric to PSS solution-oriented?

RQ2: How can a large manufacturing incumbent bridge exploration and exploitation?

The design of the study

The study involved two steps. In the first step, the researchers worked with a large manufacturing company in the construction and transportation industry. In strategic documents and internal communication, the company's leaders had expressed a desire to become a provider of Product-Service Systems (PSS). Encouraged by this goal, the advanced engineering team in the research and development function undertook projects to explore customer needs and potential PSS solutions. This step of the study examined eight cases, each involving a different PSS solution. Five of the cases included a thorough design process using need-finding and iterative design thinking approaches. Two cases focused on job site operations, and in one case, the customer approached the company with a clear and documented PSS solution need. While none of the concepts have reached a revenue-generating stage as a PSS solution, some embedded features were incorporated into downstream product development processes. The documented needs and conceptual solutions were also shared internally and used in other projects. Some of the solutions were featured in marketing and customer relations events. At the time of the case study, the company followed a Kennedy (2003) inspired four-element R&D project model consisting of the knowledge value stream, the technology development process, the product development process, and the portfolio management process. The knowledge value stream involved capturing experience and feedback in an ongoing learning cycle, which was integrated into the company's advanced engineering (AE) process. This process consisted of two separate subprocesses, an exploratory and iterative AE investigation process, and a following linear AE project process. For product development, the company followed a linear project model with distinct phases and decision-making gates, culminating in a market launch. Additionally, the company had a technology development process to close knowledge gaps and ensure the necessary technology readiness level before the product development process. This technology development stream also followed a linear project model and linked between the advanced engineering and the product development model. The company's portfolio management approach aimed to operationalize the strategy and orchestrate between the four elements in the R&D project model. The project model had, by design, a distinct gap between exploration and exploitation and a formal structure for handovers between the different elements. The study includes data from several innovation teams within one corporation from 2011 to 2020. The main author participated in six of the eight cases as responsible for explorative projects in the advanced engineering portfolio. Documentation and informal communication in the different project teams sparked interest in performing this study. Empirical data include project documentation, semi-structured interviews, and journaling notes.

The second step of the study compared the explore-exploit gap in various large manufacturing incumbents that also had successfully shifted or aimed to shift from product-focused approaches to becoming PSS solution providers. Results showed that the most promising PSS solutions integrated hardware and software, which did not align with their existing business and operational models. In this step, semi-structured interviews were conducted with six representatives from other large manufacturing incumbents in the automotive, trucking, aerospace, and information technology industries. These informants were in leading roles on the exploration side of their business or in the corporate strategy team. The interviews were conducted between 2019 and 2021, and a list of all respondents is presented in Table 1. An online survey involving the same respondents, and some more, provided additional data.

Table 1. *Responders in this study, first and second step*

Responder Company	Responder Business	Number of responders	Respondent's role
Focal firm	Construction Equipment	2	Leader of explore function
Focal firm	Trucks	1	Leader of explore function
Focal firm	Connected Solutions	2	Leader of explore function
Focal firm	Construction Equipment	5	Team member at explore function
Focal firm	Connected Solutions	3	Team member at explore function
Customer A	Construction sites	1	Open innovation director
Tech partner	Connectivity solution	1	Startup founder & CEO
Customer B	Mining site	1	Site operations manager
Research partner	Academic research and education	1	Senior researcher
Customer C	Airport ground transportation	1	Head of operations & CIO
Firm A	Automotive, tier 1 supplier	1	Leader of explore function
Firm B	Automotive, car manufacturer	1	Leader of explore function
Firm C	Automotive, car manufacturer	1	Leader of explore function
Firm D	Aerospace	1	Leader of explore function
Firm E	Trucks	1	Leader of explore function
Firm F	Information technology	1	Leader of explore function

Results

The presentation of the results is structured as the study, in two steps. The first covering the multi-case study at the focal firm and the second covering the survey-based study with leaders at other firms.

Results in the first step of the study

Table 2 describes the eight cases within the focal firm. Complexity refers to the dynamic interdependence between the physical product and digital components, such as context or process-related data. Physical product reliance refers to whether or not the solution is tied to the company's own physical products (new or existing). Investment done refers to time invested by the company itself or external partners, the cost of prototyping and test material, and the effort made in closing a knowledge gap.

Table 2. *The eight cases of PSS solutions at the focal firm*

Case	Description	Complexity	Physical product reliance	Investment done
A	Product-based: battery electric compact excavators and wheel loaders with zero tailpipe emissions	Low	High	High
B	Process-based: autonomous, electric, connected transport solutions, reduced carbon footprint, and reduced operating cost	High	High	High
C	Process-based: A combination of passive and active safety-enhancing features on jobsites, providing site surveillance and data collection and active safety on moving equipment and workers on the ground	Low	Low	High
D	Product-based: Hardware and software bundle to proactively	Low	Low	Low

	inform vulnerable road users about speed and direction of large vehicles (truck and trailers)			
E	Process-based: Productivity-enhancing, predictable, safe, and driverless transport of material on a consistent and confined route	Low	High	High
F	Process-based: An autonomous, electric, and connected truck for short-distance transport of goods on public roads. Orchestrated and manually operated remotely from a control tower when needed	High	High	High
G	Process-based: An autonomous, electric, and connected transport of people and goods. Enabling zero-emission, safe, predictable, and convenient transportation in a confined space	High	High	Low
H	Process-based: A solution for building material recycling on urban construction sites. A combination of several physical components enabling reuse of concrete and reduced truckloads on roads. Reducing traffic, carbon footprint and cost.	Low	Low	Low

All eight cases were reviewed with the following five perspectives to understand what helped and what caused problems in the progression of the conceptual solutions:

1. What problems and opportunities were identified?
2. Why did the conceptual PSS solution require another business model?
3. What PSS design activities were performed?
4. What roadblocks hindered the solution from getting further?
5. What enablers increased the likelihood of success?

Review perspective 1: problems and opportunities

Tailpipe emissions pose significant challenges for indoor and zero-emission zones. A company's carbon footprint directly affects its fuel efficiency, operational costs, and sustainability goals, which can significantly impact its competitiveness in certain markets. Governments are increasingly using carbon pricing as a tool to control carbon contribution and combat climate change. Safety is a major concern for the industry, with accidents resulting in lost uptime, decreased productivity, injuries, fatalities, and a lower quality of life. Competitiveness goals aim to reduce costs, enhance efficiency, increase productivity, and meet the demand for predictability and convenience. Sustainability goals aim to decrease resource usage, minimize waste, and limit carbon contribution. However, selling safety as a product feature has yet to be widely considered due to ethical considerations, leading to lost opportunities to improve safety on customer job sites. Taking a broader perspective that considers the entire site as a problem space provides opportunities to solve safety issues that customers value and desire. Technological advancements enable disruptive solutions, particularly when combining automation, electrification, and connectivity, to create innovative Product-Service System (PSS) solutions. Electrification can help eliminate exhaust emissions and enhance efficiency, while remote control, automation, and autonomous machines enable driverless operation and reduced operator costs. Combining these solutions adds a degree of freedom to the design process, allowing for the replacement of larger machines with smaller ones. Connectivity allows for orchestrated machines to work together in a process, optimizing electric machine charging and reducing stops and waiting times with dynamic site control. Technological advancements such as sensor accuracy, machine learning, low latency connectivity, and wearable technology provide an information layer that no longer requires human input. Physical artifacts and digital twins can integrate into an intentional and collaborative PSS solution, where partners contribute their expertise and continuous learning is shared. The construction and transportation industries have vast opportunities to explore in this regard.

Review perspective 2: business model

The company's business model centered mainly around its products, with additional vertical services such as telematics data subscriptions, machine service agreements, and financing. However, the sales structure added complexity, as it varied across dealerships and market regions, depending on the focus of the products. This structure did not align with the company's aspiration to become a total solution provider. At the time of the study, the company did not have any customer-facing divisions offering integrated product-service systems (PSS) solutions, and the telematics services department had no direct revenue stream. However, the company made strides to address these issues by establishing an autonomous solutions business unit in 2020 and an electromobility unit in 2021. The PSS concepts developed were either product-oriented, with hardware and software components, showing promise for pay-per-use business cases, or process-oriented, with interdependent physical artifacts and digital services in complex operations, showing promise for pay-per-performance or pay-per-result business models. Nonetheless, solutions not dependent on the company's existing products could have been offered as pure services but were not adopted internally because they did not generate additional sales volumes for the existing product range. In summary, while the company's business model initially focused on products with added vertical services, its sales structure was not aligned with its aspiration to become a total solution provider. The recent establishment of autonomous solutions and electromobility entities indicates the company's commitment to this goal. Nonetheless, the company needs to develop solutions that can generate additional sales volumes for the existing product range and offer pure services that are not dependent on its products.

Review perspective 3: PSS design

In this study, five of the cases examined involved project teams utilizing engineering design skills for exploration-oriented work, specifically, innovation engineering. This required a deep understanding of contextual challenges, technological and non-technological opportunities, and customer needs. Students were sometimes involved in the exploration work, providing a beginner's mindset, curiosity-driven approach, and time to understand contexts and user needs. Collaboration with customers was crucial, especially in cases where the partnership extended from idea to evaluated prototype in the customer's process. In some cases, complete customer job sites were studied to enable a more informed and holistic intentional PSS design journey that included multiple perspectives, such as predictability, productivity, and sustainability lenses. The solution space embraced opportunities from technological and behavioral disciplines. The study found that projects that adopted a holistic perspective and remained focused on solving the same problem but allowed pivots from one possible solution to another were more likely to succeed.

Customer partnerships also led to better team performance by providing information, access to job sites and users, and sometimes even having customer representatives participate in the design process. For example, one safety-oriented customer shared detailed information about their operations and long-term plans and actively participated in analyzing real-time data to identify potential risks for accidents, leading to the innovation team designing an integrated solution that utilized the gathered data to make necessary adjustments.

Most of the concepts in this study received attention from customers, competition, and media and were showcased in various marketing events, both internally and externally. External openness generated conversations and several industry actors expressed interest in collaborating to take the presented concepts further. Start-ups with emerging technologies and related in-depth expertise not available within the company were valuable partners. Although the urban mining concept remained on the company's future-oriented roadmap, it was not considered relevant by corporate leadership at the time of the study.

Review perspective 4: Roadblocks

While separating knowledge-building from industrialization-related activities can benefit the R&D process, it can also cause customer frustration and lead to a loss of valuable insights. In a traditional stage-gate process, tacit knowledge is often not captured over time or from external partners. The case studies revealed roadblocks to progress, as shown in Table 4. However, when project teams used engineering design skills for innovation engineering, they gained a deep understanding of contextual challenges, technological and non-technological opportunities, and customer needs. In some cases, students were involved in the exploration work, offering a beginner's mindset, curiosity-driven approach, and time to deep-dive into understanding contexts and user needs. Complete customer job sites were studied in some cases, allowing for a more informed and holistic intentional PSS design journey that included multiple perspectives, such as predictability, productivity, and sustainability lenses, and embraced opportunities from both technological and behavioral disciplines. Close collaboration with customers was essential when the exploration work spanned from understanding the problem holistically to validating design rationales and prototypes.

Projects that remained focused on addressing the same major challenge while pivoting from one possible solution to another were more likely to succeed with a holistic perspective. Customer partnerships led to better team performance by providing information, access to job sites and users, and even participation in the design process. For example, one safety-oriented customer shared detailed information about their operations, businesses, and long-term plans and actively analyzed real-time data to identify potential accident risks. This information allowed the innovation team to design an integrated solution that utilized the gathered data to make necessary adjustments.

Most of the concepts presented in this study garnered attention from customers, competition, and media as they were showcased in various internal and external marketing events. The external openness sparked conversations, and several industry actors expressed interest in partnering to take the presented concepts further. When start-ups provided emerging technologies and related in-depth expertise not available within the company, the value for the start-up was not only the potential to be a partner to a large multinational incumbent but also the experience gained from working with one of them. Although several promising concepts remained on the corporate's future-oriented business opportunity roadmap, they were not considered relevant by decision-making leadership at the time of the study.

Table 4. *Roadblocks for PSS concepts moving further in the company's development process*

Roadblock	**Examples of what it caused**
Disconnect between exploration and exploitation	The conceptual solution was excluded from the next development stage since only product features were considered during the selection process, resulting in the loss of original insights and a failure to address the original problem statement, and a potential market disruption opportunity
Lack of strategic alignment	Although top executives say the strategy is to offer total business solutions and increase the revenue coming from services, the way decisions are being made and success is measured still leads to status-quo customer offerings
Seeing the solution through a product lens	Even if the strategic shift is intellectually understood, it is not easy to shift orientation from product-centered to integrated

	solutions. The larger organization still carries the identity of being a product company; therefore, the integrated solutions do not make sense
Partnership management	Innovation collaboration requires new types and depths of partnerships where co-creation is central. This is even more crucial for integrated PSS solutions, as most companies lack some competence. A traditional OEM with preferred tech suppliers will not easily embrace the novel approach
Budget cuts and general uncertainty	In an exploitation-oriented organization, protecting explorative budgets can be challenging, leading to uncertainty, need for skunkworks and external funding. This uncertainty can also be difficult for some employees to handle
Ego-driven behaviors and internal politics	A specialist might be overly critical of an external tech partner as they want to protect the specialist role. A manager might want to control and command an innovation team and limit its solution space. Internal politics where the innovation antibodies are activated might do whatever it takes to hinder progress
Lacking a holistic perspective in the design process	A design process lacking sufficient zoom-out perspective may lead to a suboptimal or product-tied solution that yields insufficient revenue, risks, or loses its competitive edge.
Lacking innovation engineering skills	Not having sufficient innovation engineering skills, not having sufficient multidisciplinarity, and not understanding the exploration journey might fool a team into a solution that is not sufficient or is not sufficiently general for scaling
Culture and mindsets	Traditional organizational structure and a long history of exploitation might make it difficult for the organization to embrace the integrated solution thinking
Leadership	Short-sighted, risk-averse, and efficiency-oriented leadership. Lacking innovation understanding. Not sufficiently respected in the broader organization and not sufficiently acting as a buffer
Customer relations	To involve customers in the integrated PSS solution development, open and collaborative relationships are required throughout the journey. Handovers from a more collaborative stage to a more transactional stage in a disconnected organization may confuse or disrespect a customer who has been deeply involved and engaged

Business model	The integrated solution contains elements that require a new business model, and the rest of the organization is not prepared for it
Lack of data-driven development	Without enough quantitative data from the exploration-oriented work, it might be opinions rather than facts that determine whether the concept is promising or not
Lacking customer understanding	Not fully understanding the customer's business can make it difficult to understand the competitive advantage and the potential business viability

Review perspective 5: Enablers

The part of the organization responsible for six of the cases had built a good understanding of how to work with explorative innovation as part of the company's innovation model. In these cases, there was a small but dedicated budget, a shared mindset, systematic tools, a process, and a global network of both doers and supporters. Creative ways to increase both budget and workforce through public funding and collaboration with academia enabled these teams to keep going even when executive management did merely tolerate but not support the initiatives. In addition, a substantial amount of time was spent sharing information with the broader organization and developing business development and cost analysis competencies so that product owners and product planning teams would understand the opportunities. This well-prepared and transparent way of selling the concept internally and "crossing the internal chasm" (Moore, 1991) within the incumbent enabled the exploration work to continue despite budget cuts and lacking resources. In Table 5, the identified enablers are listed.

Table 5. *Enablers for PSS concepts moving further in the company's development process*

Enablers	**Examples of how it worked**
Extensive documentation and presentation of the holistic solution	Coming from product-centric documentation and learning about the integrated PSS solutions gave many employees a broader understanding of the customers and their needs. With the needs in focus, the "zoomed out" solution made sense
Sustainability and circularity included in the initial problem statement	Anything pointing at the company's commitment to sustainability and the circular economy was good marketing, and even an early conceptual prototype worked well to tell the

	story about the company's values
Executive leadership at both the company and the customer staying involved and informed	Executive management at the customer and executive management at the incumbent wanted to progress and asked high-level direct reports about status, which was an effective insurance against budget cuts
Large key account customer involved in the intentional PSS design	With a large important customer involved already from the beginning, executive managers in the company also got interested, and therefore, explorative innovation was tolerated
The targeted use cases well-defined and documented	Thanks to well-documented research and benchmarking leading to concise, targeted use cases, it was easy to get the broader organization to understand the rationale behind the solutions and support the design process
Team is multidisciplinary and have innovation engineering skills	With deep competencies in several disciplines and the ability to work iteratively and in an agile way, the team could overcome many roadblocks and keep progressing despite a lack of funding, resources, and support from the broader organization
Using student teams (capstone and M.Sc. thesis) for explorative innovation initiatives	Students provided perspectives, research, documentation, and working hours that were not available within the company
External funding securing additional workforce and purchase of components	The external funding was tied to research and work packages which protected projects from being eliminated due to budget cuts and short-term focused prioritization
A small portion of the R&D budget consistently secured for explorative work	The investigation budget remained untouched through several budget cuts as it was isolated from the product lines, allowing explorative innovation initiatives in collaboration with academia and other partners which enabled external funding
Smaller corporate sites showing openness and interest in radically new PSS concepts, even when not having resources	Unlike the large corporate campuses where the R&D organization was isolated from sales, production, and aftermarket colleagues, the small sites embraced explorative innovation initiatives in an open, inclusive, and more entrepreneurial manner
Leadership functioning as a buffer and providing "aircover" to the team	In an organization where innovation work is considered non-essential, it is crucial that there is aircover and that the individuals providing air cover understand what the team is trying to accomplish
Thanks to external marketing, events	Arranging external events where conceptual prototypes are being presented together with stories about the future is an

management felt they had to act as if they supported the initiative	effective way of keeping an explorative innovation initiative alive
The customer partner being used to PSS solutions, making the project feel less risky	Involving a customer partner that has experience purchasing PSS solutions (pay per use, pay per performance) can help internal skeptics to dare to try
With deep customer understanding, the team can narrow in on an initial solution scope that is convincing and later expand from there	Instead of telling the full story about the integrated PSS solution in the future, the team might have identified how to begin with a minimum viable product that all colleagues can understand, and the customer is willing to pay for. Once that is in place, it might be possible to expand to a more value-generating, or even market-disrupting PSS solution

In summary, it is necessary for leaders in large manufacturing incumbents to understand that the exploration work is vastly different from how their optimized exploitation work is conducted. It is also essential to understand that exploration is a longitudinal knowledge-building journey where one innovation team travels together and builds knowledge together. Through the journey, the innovation team members learn about themselves and their strengths and weaknesses. Furthermore, they establish a shared mindset, and they build and mature shared knowledge together. The team members establish an interpersonal connection that is valuable and possible to build on. If possible, the team should be allowed to keep moving without interruption until they arrive at a natural stop in their journey, not stifled by specific stages and gates in a linear process. Making it possible to transparently follow the innovation team's work and allow for them to have flow in their divergent, convergent journey is a way to give the team the freedom that maximizes its performance while still having oversight into the exploration journey.

Results from the second step in the study

Insights from interviews with representatives from other large manufacturing incumbents are combined and summarized to draw conclusions on similarities and keep the respondents and their employers anonymous. All interviewees were responsible for explorative innovation initiatives based at a corporate innovation hub (Amann et al., 2022) or the corporate's global headquarters.

A few general observations regarding the leadership that the interviewees reported are:

- When executive teams have a majority of members with a mechanical engineering background, they tend to underestimate business opportunities (or threats) with software and digital technology,
- With an executive team focused on near-term financial results, long-term investments will never "feel" good, and high-risk/high-reward initiatives lose against incremental improvements that are more predictable (low-risk/low-reward),
- An executive management team with the competence and conviction to communicate both near-term performance and the importance of doing "uncertain risk-taking things" is helpful for the exploration efforts. A "both-and" leadership that emphasize the importance of both quarterly results and 10-year plans provides stability for the entire ambidextrous organization.

The gap between exploration and exploitation
One of the informants explains the conditions within the corporate like this:

"The cultural clash between explore and exploit teams should not be blamed on any part of the organization and not ignored. Often executives on the very top understand the need for ambidexterity; it is on the middle management level where the problems occur. Middle managers who have been with the company for maybe 20 years, working on their careers, managing internal politics, and protecting the predictable, comfortable status quo."

The differences between exploration and exploitation mindsets and ways of working are, in all cases, bridged by the leadership on the exploration side. Leaders of innovation teams translate between the two quite different subcultures and constantly attempt to create mutual understanding and connection. While the innovation team will "feel" the opportunity because of their shared and tacit knowledge built during the exploration work, their exploitation-wired colleagues will want to see evidence where both potential and risk are quantified, often on a detailed level, since this is what they see from all exploitation initiatives. An approved and funded exploration opportunity needs to be protected and internally maneuvered continuously to mitigate command-and-control behaviors, budget cuts, unnecessary rigid legal paperwork scaring external partners and slowing down progress, and the impact of multiple risk-minimizing rather than risk-managing perspectives from various parts of the organization. An organization unwilling to trust the innovation team to "do their thing" can delay and kill promising solutions and lower its attractiveness as a partner, supplier, and employer.

With colleagues being full-time occupied with exploitation activities, it can sometimes be smart to leave them alone until your concept is proven and can be demonstrated. When they see a concept that is solving an existing major problem that they earlier agreed needed to be solved, there will be an openness to the solution, especially when the innovation team acknowledges that a conceptual solution created with Raspberry Pi is not what will end up on the production line. When the exploration side of the organization shows exploitation side understanding and demonstrates empathy for their stressful work, trust will enable collaboration and bridging between the two.

The need for a buffer

The responsibility mentioned above of the exploration side's leader to bridge over to the exploitation side is recognized in all cases and by all interviewees. A hierarchical structure with a command-and-control culture causes hindrances to the exploration efforts. One example is when the company's culture leads to high-level executives being treated as "the smartest person in the room," not open to explorative "what if…" conversations, and not demonstrating humility or curiosity. This culture leads to a very inflexible innovation process, where the iterative exploration work becomes stifled. This is common and limits the potential to find the best and most profitable solution. The culture is difficult to change as it has been ingrained in the organization for decades, even centuries back, and executives might be blind to it. One way to tackle this challenge is to ensure a high level of diversity in the executive management team. Here, diversity refers to backgrounds from several types of organizations, being successful in different ways, and surviving over innovation cycles. It takes very insightful and strong leadership to constantly ensure diversity, as many incumbents have a strong culture of conformity and compliance. There is no need for the exploration side of the organization to wait for the executive management level to "get it." Their contribution can be successful and value-adding to the company even without that level of insight on the top. Then the leader taking on the buffer role is indispensable. The buffer role is the often-unrecognized role of a leader in charge of innovation teams tasked with explorative innovation work to translate, bridge, and create mutual respect, mutual interest, and mutual understanding between exploration and exploitation. This individual needs to have both the entrepreneurial skills and the ability to lead a high-performing innovation team and have solid competence and experience from traditional product development work (Wright, 1998). One respondent used the term "corporate whisperer" to describe one key responsibility of the buffer. The buffer role is crucial to keep an innovation team motivated, high performing, ambitious and brave, and at the same time, build bridges over to the colleagues that eventually need to become part of the initiative to end up in a cost-reducing or revenue-generating stage. Without the buffering between exploration and exploitation, there is a risk that the broader organization will be antagonistic toward the innovation team and skeptical about both concepts and partners - i.e., the not-invented-here syndrome (Amann et al., 2022).

It is observed that even with an executive management team that intellectually understands the threat of disruption due to software and digitalization, there is a tendency that they collectively conclude that the threat is far out in the future. Unfortunately, digital technologies do not develop linearly, so waiting until the threat is visible in the financial results can be risky. By ensuring that exploration practice is mastered by few but known by many, the ability to "lead from the future" is secured. This is, in all cases, a responsibility put on the individual holding the buffer role - as part of being the corporate whisperer. Seeking in literature for examples of buffer roles led us to the legendary Xerox PARC and the individual with the buffer role, Bob Taylor (Hiltzik, 2000). He once said: "The only way to get PARC to do the best research was to hire the best individuals and then leave them unburdened by directives, instructions or deadlines." Similar views were expressed by several informants in this study, for example, a corporate innovation hub leader in the automotive industry explained:

"Cloud services are being developed in the same process as the windshield wipers. That is not going to work. How do you develop software in a development process for hardware? And how do you make the hardware guys understand why that is wrong?"

This informant had been leading the innovation team for several years and focused a lot on acting as a buffer and translator between the explore team and the larger organization, for example invested substantial time in understanding challenges in the manufacturing function and focused exploration work on solving those problems, to make the larger organization understand the value of the exploration team. Furthermore, this informant described the conditions for a corporate innovation hub leader like this:

"If you are looking for recognition and appreciation, this is not the job. You will need to represent the corporate in front of your local team - and in a way that motivates them. You will need to represent your local team when you talk to the mothership - and in a way that makes them leave you alone. Your role is to connect and translate for two sides that cannot understand each other." If the executive leadership wants to maximize the potential of the company's exploration efforts, the general understanding of the differences between explore and exploit needs to be increased across the broader organization. By that, the buffering role becomes a shared responsibility and not one individual's burden.

Partnering for competence and speed

Large manufacturing companies moving towards integrated product-service systems with competitive digital components may require a 10-year capability-building journey. To shorten time-to-market, partnering with software companies that have top-notch software development talent can be advantageous. Although partnering with start-ups possessing domain expertise and a fast-moving mindset is a reasonable strategy, internally appointed experts often feel threatened and may exhibit "not-invented-here" syndrome. While an internally appointed expert may not be the best in the world, they may still perceive themselves and be perceived by colleagues as a guru in an organization underinvested in that domain. An interviewee recommended not appointing a "center of excellence" unless it spans both exploration and exploitation work. Experts can focus on knowledge building, deep partnerships, and co-creation when given exploration responsibility rather than feeling threatened or defensive. All interviewees agreed that the company's ability to build strong and deep partnerships depends on the larger organization's attitude toward the ecosystem. Competence, collaboration, and generosity help to establish a positive perception while being perceived as complicated, unapproachable, and greedy does not. Mutual trust is crucial for successful exploration work leading to radical innovation (Brattström et al., 2015). Learning to collaborate with external partners' most valuable talents might make both leaders and experts feel incompetent, which ought to be acceptable when such talent combined with the incumbent's strengths can lead to breakthrough innovation. As one of the informants expressed it:

"Innovation is a team sport, and successful collaboration can happen with almost anyone if you just get the right energy and motivation - so what really hurts an innovation team is when the headquarters says that it needs to match into this perfectly made matrix and the legal contract needs to be nitty-gritty perfect to the point on all 200 pages."

Embracing innovation engineering skills as corporate core

Innovation engineering is a team-based exploratory process that involves various approaches, tools, mindsets, and skills to address open-ended, ambiguous, or complex problems, generate new knowledge, and potentially radical innovations (Sidhu, 2019). When a team practices innovation engineering, the team members embark on a joint exploration journey aimed at achieving a shared understanding of an agreed-upon problem and developing new knowledge that can potentially lead to one or several satisficing solutions (Simon, 1956). Innovation Engineering is best performed by multidisciplinary T-shaped innovation teams when they pursue projects of explorative nature with ambiguous problem spaces and wide-open solution spaces. The exploration journey includes behavioral, social, and technological possibilities.

As the industry evolves towards autonomous, electric, and connected solutions, it becomes crucial that companies integrate their hardware and software, edge, and cloud components, as a complete product service system solution, sometimes enabled by external partnerships. A holistic end-to-end design process is needed, and competencies and capabilities are developed as part of the learning journey. A discrete handover from the "early phases" team to other leads to a loss of tacit knowledge and time. Large manufacturing incumbents are good at documenting and reporting organizational efficiency data, such as hours and money spent, and systematically document and store product-related data. Information that explains addressed problems, conceptual solution intentions, and design decision rationale is rarely systematically documented. Adopting an end-to-end approach, from the initial need finding to the first minimum viable product in the hands of the first customer, is how some incumbents overcome this challenge.

With a conscious shift towards intentional PSS design, the organization will shift towards a faster, more flexible, and delegated decision process that allows solutions to reach the first customers fast enough and avoid the spinal reaction to take control in a traditional, hierarchical command-and-control manner. Data from the interviews show a pattern that leadership within large manufacturing incumbents confuse market dominance with disciplinary competence. Understanding and accepting what you are good at and what you need partners for is not hard if you keep your ego in check. Also, understand that the most important question to an innovation team is "What have you learned?"

"If a large manufacturing incumbent would look at every dollar spent versus its performance, it would be noticed that a lot of money goes to unnecessary command-and-control, feeding of egos, and individuals' urge to climb the career ladder."

Making innovation engineering teams reach their maximum potential

Motivation in an innovation engineering team comes from doing what they are passionate about, challenging the status quo, and doing truly difficult things. Typical individuals mastering innovation engineering skills tend to have no interest in titles, no wish to learn how to navigate corporate hierarchy, and no need for personal development plans and such, but have instead a knack for solving difficult problems and being involved in complex and big challenges. This type of employee will stay motivated and perform well if they get the freedom to move ahead as fast as possible, contribute with measurable value, and learn simultaneously. Allowing a free flow, avoiding unnecessary follow-up, and reporting so that the team can focus and deliver is recommendable. Leadership that understands the characteristics of exploration work and realizes its equal importance to exploitation makes information exchanges and interactions more fruitful. To embrace exploration means more than tolerating it and letting it fight for its existence, which tends to be common in large manufacturing incumbents. All respondents mention the multidisciplinarity, the T-shaped individuals, and the rebel talents as instrumental to successful exploration work. As an entrepreneurial enterprise, providing the right environment for the innovation team to create intentional PSS solution concepts can make the company stay relevant and competitive over decades and centuries—a better investment than trying to make it fit into an operational model optimized for exploitation.

One of the respondents described how it was taken for granted that the gap between exploration and exploitation should be closed by the exploration team. Not only were they expected to perform high-quality exploration work and demonstrate refined and convincing concepts, but they also needed to understand the working conditions for their colleagues doing exploitation work. The leader of the innovation team could bridge the two if they have that experience. Still, an enterprise striving to be truly entrepreneurial would bridge the gap better and help the shift from P to PSS by spreading the understanding about both exploration and exploitation to the broader organization.

Discussion

Several times in interviews with leaders and employees within the companies, the term innovation theater (Blank, 2019) has come up. Blank (2019) describes it in the following three ways:

1. Organizational theater - often guided by external management consultants, leadership seeks to solve the challenge with innovation through reorganization alone,
2. Innovation theater - activities like hackathons, design thinking classes, and innovation workshops with an emphasis on creative confidence, where leadership seeks to solve the challenge with innovation through activity experiences only,
3. Process theater - reforming and recasting processes and metrics optimized for exploitation execution, where leadership seeks to solve the challenge with innovation solely with reformed processes.

What might help against innovation theater is explicit communication regarding the relation and differences between exploring and exploiting in an ambidextrous organization. Establishing strategic alignment (Tushman & O’Reilly, 2019) regarding the identity and mindset shift from product-centric to PSS solution-oriented organization is also effective against innovation theater.

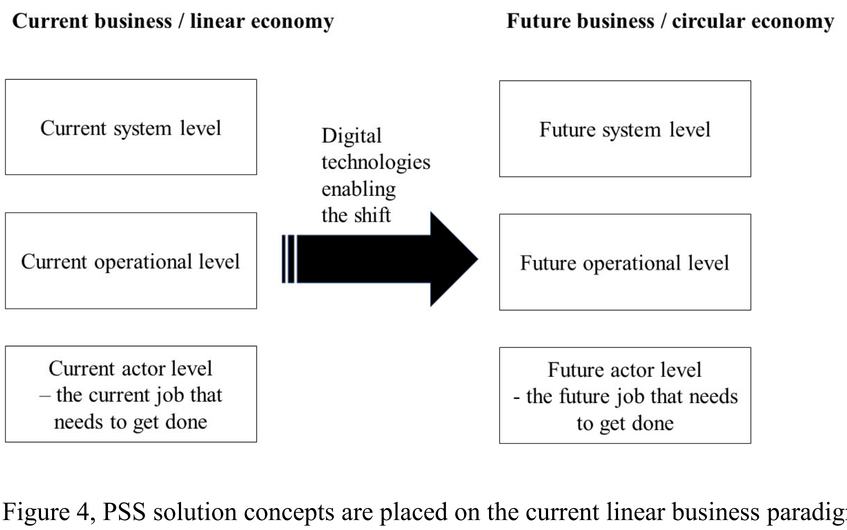
A large manufacturing incumbent can become an entrepreneurial enterprise through a clear overall plan, with a balance between near-term and long-term competitiveness, managed in a transparent, inclusive, and concerted manner. This study focuses on bridging exploration and exploitation to expedite the progression of promising PSS solutions from conceptualization to revenue generation. Intentional PSS design is suggested as a means for the explore team to shape the company's future and provide sensemaking to the broader organization. When left to pioneer novel and promising PSS solutions alone, the explore team's good intentions and bold ambitions can result in confusion, frustration, or disconnect to the larger organization. Even with a clear strategic intent to shift the business towards more integrated solutions, executive leaders may fail to communicate and cascade the message throughout the larger organization. Failure to take conceptual PSS solutions to the revenue-generating stage is a waste of effort and investment.
In this study, the innovation team must excel in innovation engineering skills and work effectively as a non-hierarchical team. The surrounding organization must also understand the unique characteristics of exploration work, which differs starkly from the linear stage-gate process. Educating decision-makers and the broader organization about exploration can help enable ambidexterity to be more than just executive management talk. The buffer role is crucial for effective innovation teams, leading the team without creating a hierarchy in the team and providing air cover for free-flowing problem-solving and iterations. Command-and-control behavior limits breakthrough innovation and disengages high-performing team members, so such executive leadership behavior must be contained by the individual with the buffer role. The buffer also acts as a "corporate whisperer" connecting the explore and exploit teams and understanding the organization's culture, operational model, and power structures. A common challenge across large manufacturing incumbents is that exploration work is viewed as non-strategic, incomprehensible, and unrealistic.

This research identifies two approaches for innovation teams to improve communication and connection with their organization. The first approach, inspired by a new discourse on PSS design by Lugnet et al. (2020), involves intentional PSS design to shape the future and evolve the solution from the current to the wanted state intentionally. The second approach, inspired by "the Wonder Bread Model" applied at HP by one of the authors, is a tool for making informed and non-biased strategic decisions regarding existing customer offerings and promising conceptual solutions. These lightweight and transparent approaches can help bridge the gap between explore and exploit, as well as aid in shifting a corporate identity and mindset towards a problem-solving, entrepreneurial enterprise, as well as improving communication and connection within the organization.

Bridging approach 1: Three-level intentional PSS design

Figure 3 presents a suggested visual tool for intentional PSS design based on Figure 1. This tool allows innovation teams to address current needs and opportunities on three distinct levels while preparing for solution evolution over time. First, the tool facilitates zooming out from identified user needs to operational and systemic levels, enabling the team to focus on current needs and possibilities before exploring solutions that respond to a future scenario. After exploring current and future solutions, the team can continue to explore how to get from the current to the future with the help of digital technologies. Finally, this approach allows the organization to build on existing knowledge and relationships while offering new innovative PSS solutions.

Figure 3. Suggesting a *model for intentional PSS design (inspired by Lugnet et al. 2020)*



In Figure 4, PSS solution concepts are placed on the current linear business paradigm and the desired future circular business paradigm levels. The levels represent the actor, process/operations, and system levels. The intentional PSS design approach considers these levels to identify solutions to current problems and design for solution evolution. By gathering data from both products and contexts, innovation teams can use the intentional PSS design approach to imagine different future scenarios and future technology advancements. Digital technologies enable the shift from a product-centered to a PSS-oriented organization, facilitating solution evolution. Therefore, it is important for innovation teams to use their explicit and tacit knowledge collectively on an explorative journey. The intentional PSS design mission is, in this example, “future circular,” but it can also target net-zero carbon contribution or zero accidents. Using the intentional PSS design approach, large manufacturing incumbents can evolve solutions with partners with greater customer value, impact, and revenue.

Figure 4. *PSS concepts mapped vs. current linear, and future potential circular economy*

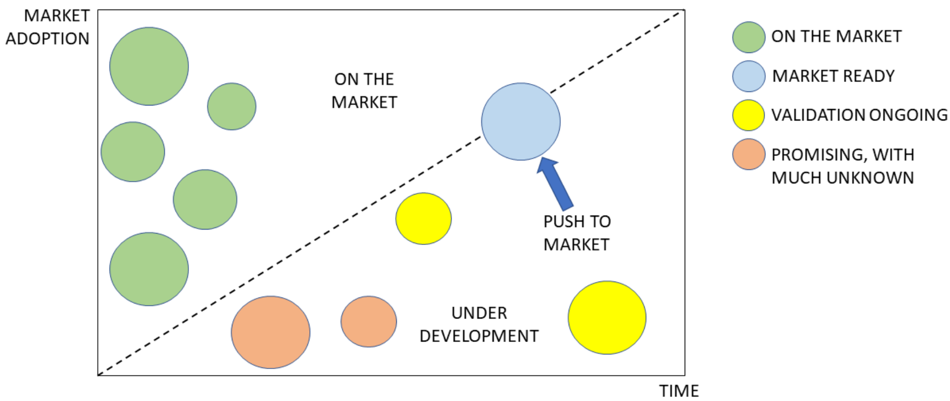
Case	Current Linear	Digital technologies enabling the shift from linear to circular	Future Circular
A	Actor level	Sensors and devices. Log data. Cloud/edge computing. Network. AI / ML. Digital identity of entities. Blockchain.	Actor level
B	Operational level	Sensors and devices. Log data. Cloud/edge computing. Low latency network. AI / ML. Digital identity of entities. Digital twin of site operation.	Operational level, System level
C	Operational level	Sensors and devices. Log data. Low latency network. Digital identity of entities.	Operational level, System level
D	Actor level	Sensors and devices. Log data. Network.	Actor level, Operational level
E	Actor level	Sensors and devices. Log data. Cloud/edge computing. Network. AI / ML. Digital identity of entities.	Operational level
F	Operational level	Sensors and devices. Log data. Cloud/edge computing. Low latency network. AI / ML. Digital identity of entities. Blockchain. Digital twin of transport flow.	Operational level, System level
G	Operational level	Sensors and devices. Log data. Cloud/edge computing. Low latency network. AI / ML. Digital identity of entities. Digital twin of site operation.	Operational level, System level
H	Operational level	Sensors and devices. Log data. Network. Digital identity of entities.	Operational level, System level

Actor level   Operational level   System level

Bridging approach 2: Standardized solution visualization for decision making

One of the authors worked at Hewlett Packard from 1985 to 2005 and during the time she was director of business strategy she and her team developed *The Wonder Bread model*. This model was instrumental for HP during the time the company had set a strategic intent to extend its business model from being purely product-centric to a more holistic focus on solving customers' problems. By starting with a structured vertical business analysis and researching beyond the traditional core, HP utilized the Wonder Bread model to visualize market size, viability, executability, and potential market of promising concepts. This model also allowed them to follow the development of a concept's market readiness over time and make informed decisions about both existing and potential customer offerings. In the model, the existing and promising customer offerings are all visualized as colored balloons (therefore the name of the model) to help nonbiased decision-making. Figure 5 shows a simplified standardized solution visualization for decision making, inspired by HP's Wonder Bread model.

Figure 5. *A conceptual solution visualization model.*



At HP the following data (and more) was continuously collected to track the potential, the maturity, and other information about promising concepts:

- Market value; in terms of potential market size and potential revenue
- Time horizon; in terms of project age and estimated time to market (in years)
- Organizational effort; in terms of the number of employees engaged and part of the organization involved
- Changes since last month (none, start, stop, redirect)
- Technical risk (low, medium, high)
- Business/market risk (low, medium, high)
- Organizational risk (low, medium, high)

The Wonder Bread Model was applied to the above data (and more), wherein the size of a balloon represented market value and the color represented maturity, encompassing diverse uncertainties and risks, including partners and business models. This model was a powerful tool, allowing existing offerings and promising new concepts to be visualized on the same chart, facilitating transparent strategic decision-making, and enabling the organization to mobilize to bring new concepts to market. The model provides a means of visualizing value and maturity quite intuitively, and over time, so that decisions can be made based on rich information. Its simplicity enables engagement from the broader organization so that they can contribute to bringing emerging opportunities toward a revenue-generating stage. Visualizing existing and potential customer offerings in one graph can help large manufacturing incumbents to bridge the gap between exploration and exploitation. It can also help the entire organization to shift its identity and mindset from a product manufacturer to a solution provider.

Both approaches are suggested to help bridge exploration and exploitation and help promising concepts “cross the internal chasm” in large manufacturing incumbents. Additionally, a strategic alignment with a "both-and" leadership across the corporation is necessary on all levels. To facilitate the transition from being a pure product manufacturer to one who provides integrated hardware/software solutions, we recommend adopting Bertoni et al.'s (2012) six fundamental transitions for knowledge management. These include:

1. Moving from weak to potential ties: Encouraging individuals to connect and collaborate in the search for innovation and novelty, rather than relying solely on formal relationships,
2. Deriving public benefits from personal actions: Utilizing lightweight technologies for meaningful knowledge sharing without imposing additional work,
3. Moving from predefined to emergent structures: Avoiding high-threshold control structures that limit innovation,
4. Moving from lookup to exploration: Assisting knowledge workers in exploring beyond known information to discover new solutions,
5. Moving from directional to intersectional innovation: Encouraging collaboration across fields and cultures to create innovative ideas,

6. Moving from teams to crowds: Keeping social ties loose and promoting diversity of knowledge sources to facilitate open and collaborative knowledge sharing.

To implement these transitions effectively, it is crucial to foster deep partnerships internally and externally, requiring a more social engineering and community-building approach to knowledge sharing, not only for exploration and innovation activities but for all knowledge workers to share what is and what might be.

Conclusion and Future Work

The shift from product-centric to product-service system solution-oriented presents challenges for large manufacturing incumbents. A lack of an overall plan that includes organization, process, and innovation activities, and the separation between exploration and exploitation activities can cause unnecessary roadblocks, lost business opportunities, and wasted time and resources. By providing insight into both roadblocks and enablers, a shift towards the new without abandoning the corporate legacy might be feasible.
The study aimed to answer two research questions: (1) Why do promising PSS solutions get stuck or killed in large manufacturing incumbents' development processes, despite a strategic intent to shift from product-centric to PSS solution-oriented? and (2) How can a large manufacturing incumbent bridge better between exploration and exploitation and facilitate the shift from product to PSS?

The study found that decision-making bodies and individuals in large and mature product manufacturers are highly skilled and experienced in the traditional, stage-gate product development process but need to be more skilled in agile development and continuous upgrades, like the software industry. The effort to protect and defend the exploration activities is time-consuming and challenging. Increasing general knowledge about the differences between exploration and exploitation work, demonstrating respect, and facilitating transparency between the two can help with performance and employee satisfaction. Innovation engineering skills and approaches are similar across different organizations and should be communicated and documented in the enterprise management system.

Intentional PSS design can help bridge the gap between exploration and exploitation by providing transparency and rationale to the broader organization regarding specific PSS solutions' selection and how they generate value for customers and revenue for the company. Two suggested approaches are to (1) visualize the decision-making process and (2) develop a "PSS blueprint" that details the PSS solution's technical and commercial aspects. To facilitate the shift from a product to PSS and from a product manufacturer to an entrepreneurial enterprise, strategic alignment and ambidexterity must be infused into the organization, i.e., both the exploration and exploitation mindsets and ways of working should be understood and embraced by the larger organization. The buffer role is an important connecting and translating resource within the organization, particularly in the early days.

Future Work

This study explored components and documented previous research insights that come from successful realignments. A future study could combine intentional PSS design with the plan on an executive level infused in the entire enterprise and observe how that helps promising concepts get through internal processes and decision bodies.

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ABSTRACT

This thesis explores how large manufacturing incumbents can future-proof themselves by infusing ambidexterity throughout their organizations. In today's rapidly evolving business environment, companies must excel at both exploiting current opportunities and exploring new ones. However, while many large manufacturing companies excel at making incremental improvements, they often struggle to find new ways of creating value for customers, resulting in missed opportunities to stand out in the market through radical innovations. This thesis proposes a methodology consisting of four foundational principles for strengthening the innovation capability of large manufacturing incumbents. The thesis also suggests the term ”innovation engineering” to differentiate exploration and exploitation and to demystify exploration-oriented work for the larger organization. Furthermore, it also presents the concept of ”intentional PSS design” as an approach to incorporate future aspirations and current capabilities into an evolutionary design process, connecting current and future opportunities, limitations, and possibilities. The thesis proposes tools to support innovation engineering teams in their exploration journeys, which serves to bridge the gap between exploration and exploitation. Through this research, readers will gain a deeper understanding of the potential of innovation engineering and infused ambidexterity, allowing large manufacturing incumbents to adapt to a changing environment and reinvent their ways to meet customer needs. This thesis proposes practical ways to transition from a product-selling to a problem-solving (PSS-solution-selling) enterprise, enabling companies to contribute to solving wicked problems of today and future societal challenges. This thesis will reveal how large manufacturing companies can prolong their lifespan and remain relevant in a rapidly changing business landscape.

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