# Fostering insights and improvements from IIoT systems at the shop-floor

*A case of industry 4.0 and lean complementarity enabled by action learning*

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# Fostering insights and improvements from IIoT systems at the shop-floor: A case of industry 4.0 and lean complementarity enabled by action learning.


## Abstract

**Purpose**: This paper investigates how manufacturers can foster insights and improvements from real-time data among shop floor workers by developing organisational "learning-to-learn" capabilities based on both the lean- and action learning principle of *learning through problem-solving*. Secondly, the purpose is to extrapolate findings on how action learning can enable the complementarity between lean and industry 4.0.

**Design/methodology/approach:** An insider action research approach is adopted to investigate how manufacturers can enable their shop-floor workers to foster insights and improvements from real-time data at VELUX.

**Findings:** Our findings report that enabling shop-floor workers to utilise real-time data consist of developing three consecutive organisational building blocks of (1) learning-to-learn, (2) learning-to-learn using real-time data, and (3) learning to learn generating real-time data - and helping others to learn (to learn).

**Originality:** The study contributes to theory and practice by firstly demonstrating that a learning-to-learn capability is a core construct for manufacturers seeking to enable shop-floor workers to utilise real-time data-capturing systems to drive improvement. Secondly, the study outlines how lean and industry 4.0 complementarity can be enabled by action learning. Moreover, the study allows us to deduce six necessary conditions for enabling shop-floor workers to foster insights and improvements from real-time data.

**Keywords:** Lean, Industry 4.0, Action Learning, Industrial Internet-of-Things (IIoT), Insider Action Research, Learning-to-Learn Capability

**Paper type:** Research paper

## 1 Introduction

An emerging trend in manufacturing is embarking on a digital transformation to utilise new digital technologies to better cope with changing customer demands (Balci, 2021; Machado *et al*., 2021; Sousa-Zomer *et al*., 2020). Since many manufacturing firms have previously developed their production systems based on lean practices, there is a growing interest in supplementing and integrating lean production with digital manufacturing technologies, often referred to as Industry 4.0 (I4.0) technologies (Rossini *et al.,* 2021).

Studies investigating the complementarity of lean practices and I4.0 technologies are a research field on the rise (Bittencourt *et al.,* 2021; Chiarini and Kumar, 2020; Ciano *et al.,* 2021; Ding *et al.,* 2021; Tortorella *et al*., 2019). However, research into what facilitates the complementarity of I4.0 and lean is scarce (Demeter *et al.,* 2020). A majority of existing studies can be characterised as techno-centric since the focus is often purely on the technical implementation of I4.0 technologies, with the social aspects omitted (Buer *et al.,* 2018). Adopting I4.0 is a socio-technical phenomenon that considers an organisation's capability to utilise digital technology, specifically using the digital data generated to improve and transform business processes (Dixit *et al.,* 2021; Liker, 2020; Yilmaz *et al.,* 2021).

The extant literature indicates that the techno-centric focus associated with I4.0 can prevent manufacturers from realising valuable improvements from the increasing amount of digital data available on the shop floor and thereby not capitalising on their investment in I4.0 technologies (Rossini *et al.,* 2021; Saabye *et al.,* 2020). This is often the case if shop-floor workers are not enabled and empowered to utilise the real-time data to foster insights on improving production lines and adapting them to new products and machinery (Brown and Vondráček, 2013; Rossini *et al.,* 2021). Several operation management research studies regard applying a people-centric approach during digital transformation as imperative (e.g. Cagliano *et al.,* 2019; Marcon *et al.,* 2021). Enabling shop-floor workers to utilise I4.0 technologies is an organisational learning process (Machado *et al.,* 2021), which requires a learning-to-learn capability to supplement the existing production system (Powell and Coughlan, 2020, Saabye *et al.,* 2022). Recent research by Saabye *et al.* (2022) demonstrates that the heart of a learning-to-learn capability is the lean- and action learning principles of learning through structured problem-solving routines to foster insight among shop-floor workers and managers through an ongoing process of experimentation and reflection (Liker, 2020; MacDuffie, 1997; Machado *et al.,* 2021). Shop-floor workers' ability to identify and solve problems rapidly and independently becomes a foundational condition for developing a learning-to-learn capability to use the I4.0 technologies effectively (Brown and Vondráček, 2013; Leyer *et al.,* 2018; Liker, 2020; Saabye *et al.,* 2020).

To comprehend the qualities of action learning for enabling I4.0 and lean complementarity we are guided by Revans' (1971) theory of action and science of praxeology of cycle systems of Alpha, Beta, and Gamma and thereby extending the research of Powell and Coughlan (2020) and Saabye *et al.* (2022).

This study originates from an action learning intervention at VELUX, a Danish rooftop window manufacturer. The ambition of this action learning intervention is to empower and enable the shop-floor workers to utilise the I4.0 technology of IIoT by developing learning-to-learn capabilities. After a failed IIoT technology adoption effort, the company understood that it needed to apply a more people-centric approach to using the data generated by these new IIoT technologies (Saabye *et al.,* 2020).

This study contributes theoretically with a set of necessary conditions for IIoT utilisation and I4.0 and Lean complementarity. Specifically for enabling and empowering shop-floor workers to utilise real-time data on the shop floor to improve performance:

1. Leaders that foster a supportive learning environment.
2. Institutionalised daily learning and problem-solving routines.
3. Daily learning and problem-solving routines and IIoT technology are perceived as improvement-enabling mechanisms among shop-floor workers.
4. Shop-floor workers are trained in IIoT technology and how to decide where to set up IIoT sensors.
5. Senior shop-floor workers coach and train other shop-floor workers in problem-solving and IIoT technology.
6. A hierarchical coaching structure.

The overall purpose of this research is to provide insights into how manufacturers can enable their shop-floor workers to foster insights and improvements from real-time data. Second, to generate insights on the complementarity between lean and industry 4.0 enabled by action learning. We extrapolate these findings by adopting an intervention-based insider action research approach (Coghlan 2007; Coughlan and Coghlan, 2002; Olivia, 2019) from an action learning intervention at VELUX.

The rest of the paper is structured as follows: Firstly, we locate, within the extant literature, the challenges associated with I4.0 adoption and obtaining I4.0 and lean complementarity. Secondly, we address this challenge in practice by narrating the action learning intervention at VELUX. Finally, we reflect and extrapolate upon the emerged learning from instigating the action learning intervention at VELUX by discussing and articulating the contributions to theory and practice.

## 2 Locating the challenges in the literature

### *2.1 I4.0 (IIoT) adoption challenges*

A key characteristic of I4.0 is technologies capable of autonomous data collection and analysis based on data from networked things such as machines, parts, people, sensors, databases, suppliers, users, and markets (Buer *et al.,* 2018; Bi *et al.,* 2021). These technologies are labelled IIoT. Boyes *et al.* (2018, pp. 3-4) define IIoT as "a system comprising of networked smart objects, cyber-physical assets, associated generic information technologies, and optional cloud or edge computing platforms, which enable real-time, intelligent, and autonomous access, collection, analysis, communications, and exchange of process, product and service information, within the industrial environment, to optimise overall production value".

Thus, the potential of IIoT is product or service delivery improvements in real-time, improved productivity, reduction of energy consumption, and rapid manufacturing of new products (Boyes *et al.,* 2018; Liu *et al.,* 2019; Zelbst *et al.,* 2019). For example, setting up sensors and tags on the production lines allows the IIoT system to capture and communicate operation performance data to be analysed and displayed in real-time on the shop floor (Zelbst *et al.,* 2019). This real-time data can potentially support decision-making for problem-solving and improvement activities by providing process performance transparency among shop-floor workers (Rosin *et al.,* 2020; Wagner *et al.,* 2017).

These potentials, however, are challenging to obtain. Only 14 per cent of I4.0 initiatives were successful in 2019, according to a survey of over 1000 manufacturing companies (Yilmaz *et al.,* 2021). According to Verma and Venkatesan (2022), these adoption challenges can, e.g., be attributed to organisational and managerial challenges of job design, competencies, organisational learning, organisational development, safety and work conditions. Similarly, Cagliano *et al*. (2019) devise that adopting I4.0 technologies requires addressing people-oriented aspects. Other research emphasises that despite the I4.0 technologies can contribute with huge improvement potentials; it continues to be the people-oriented aspects of, e.g., developing and empowering employees to actively participate in problem-solving and creative innovation processes that will unleash these potentials (Demeter *et al.,* 2020; Marcon, 2021; Rosin *et al.,* 2020; Shet and Pereira, 2021; Tortorella *et al.,* 2020).

### *2.2 I4.0 and lean complementarity*

Today, lean is widely popular and embraced by academia and industry and has been identified as a powerful approach to improving production and operation enabled by both technology and the cognitive abilities of humans (Mackelprang and Nair 2010; Marodin and Saurin 2013). This has led to significant interest in research examining the complementary nature of lean and I4.0. Although a complementing link between I4.0 and lean is established, it is still a nascent research stream on the rise (Antony et *al.,* 2022). When implementing I4.0 technologies, the existing lean manufacturing system should not be ignored, according to Buer *et al.* (2021); instead, it should be used as a foundation for integrating new technologies into the system. I4.0 is not a replacement for lean thinking. Therefore, Powell *et al.* (2021) suggest a *lean first … then digitalise* approach to I4.0 implementation to avoid the digitalisation of waste. Hence manufacturers should continue to improve and perfect their lean practices when adopting I4.0 to gain the potential benefits (Rossini *et al.,* 2020). Yilmaz *et al.* (2021) also perceive lean as a prerequisite for I4.0 adoption - in a manufacturing context and elsewhere. Likewise, Demeter *et al.* (2020) propose that lean is recognised as a requirement during the early stages of I4.0 deployment. Once implemented, industry 4.0 technologies complement lean and operational performance (Buer *et al.,* 2021; Raji et *al.,* 2021). Essential for lean to act as a platform and enabler for implementing I4.0 technologies, it must be implemented as a long-term measure (Netland and Powell, 2016). Although a complementing link between I4.0 and lean is established, we find that the literature is still scarce on what facilitates this complementarity from a learning perspective.

### *2.3 Learning-to-learn as a core lean capability*

In the extant literature, lean is recognised as a superior way of organising and managing production, leading to significantly improved performance and profitability (Womack *et al.,* 1991; Camuffo, 2017; Ballé *et al.,* 2017). Moreover, lean has been defined as a socio-technical system (Liker, 2020) and a learning system (Powell and Reke, 2019) that emphasises the ability of the organisation to effectively solve problems and develop proficient problem solvers on all organisational levels (Ballé *et al.,* 2019; Liker, 2020). Developing effective and proficient problem solvers requires developing an underlying learning-to-learn capability (Powell and Coughlan, 2020; Saabye *et al.,* 2022; Smith, 1997). Recent research by Saabye *et al.* (2022) demonstrates that initialising a learning-to-learn capability built on lean thinking requires: (1) organization-wide systematic problem-solving abilities, (2) leaders serving as learning facilitators, (3) a supportive learning environment, (4) and organisational learning scaffold, and (5) knowledge about I4.0 technologies and adoption.

To further theoretically define learning-to-learn as a lean capability, this paper draws on the literature on learning-based problem solving, enabling formalisation, organisational learning, and action learning.

### *2.3.1 Problem-solving*

According to the existing research on organisational problem solving, an over-emphasis on a method-based approach and a focus on identifying and adopting preferred problem-solving tools and procedures have harmed organisational learning and process improvements (Tucker *et al.,* 2002, MacDuffie, 1997; Cho and Linderman, 2019). Instead, organisations are advised to adopt a learning-based problem-solving approach, which focuses on understanding and solving problems as contextual and addressing the social challenges that impact performance and capabilities, particularly in unpredictable circumstances (Cho and Linderman, 2019; Yoo *et al.,* 2018).

The core practice of learning-based problem solving is to address problems by applying the scientific method. The scientific method is a generic interactive learning and problem-solving process that can be defined as Deming's (1982) Plan-Do-Check-Act (PDCA) cycle, or as five distinct steps formulated by Revans (Smith 1997, p.723) of (1) conducting a survey, (2) formulating a hypothesis to be (3) tested through experimentation, (4) contrasted against the expected outcome, and finally (5) reviewed against the overall objective.

Moreover, learning-based problem solving is characterised by practising and applying learning routines and practices that ensure adherence to the scientific method, structured experimentation, and reflection (Johnson *et al.,* 2020; Rother, 2010; Shook, 2008).

### *2.3.2 Enabling formalisation*

When institutionalising new technology and work routines, shop-floor workers perceive it as either coercive or enabling (Adler and Borys, 1996). For example, suppose the shop-floor workers perceive the implementation of new technology or work routines imposed by specialists or managers to ensure compliance with rules and procedures by controlling their work. In that case, it can be classified as coercive. Consequently, the expected utilisation will not be attained. On the other hand, if the shop-floor workers perceive that new technology is designed to support them in better performing and improving their daily tasks, formalisation is defined as enabling (Adler and Borys, 1996; Liker, 2020). Ensuring an enabling perception of new technology and work routines requires organisational learning (Saabye *et al.,* 2020).

### *2.3.3 Organisational learning*

Edmondson and Moingeon (1998, p.28) define organisational learning as "*a process in which an organisation's members actively use data to guide behaviour in such a way as to promote the ongoing adaptation of the organisation*."

A supportive learning environment constitutes a condition for organisational learning. According to Edmonson (1999), a supportive learning environment makes employees feel psychologically safe disagreeing. They can freely ask naive questions, admit mistakes, raise minority opinions, reflect, explore new ideas, conduct experiments, and exchange knowledge. Moreover, an integrated part of employees' daily work within a supportive learning environment is leaders who foster contextual training, and adequate time to reflect and experiment (Marsick and Watkins, 2003; Saabye *et al.,* 2020).

### 2.3.4 *Action learning*

Action learning enables professionals to learn and grow by reflecting on their experiences while addressing real-world problems in their own organisations (Coghlan and Coughlan, 2010). Central to the practice of action learning, Revans (2011, p.85) propose, "*There can be no learning without action, and no (sober and deliberate) action without learning*".

Revans (1982) developed the action learning paradigm using the formula L = P + Q, with L denoting learning, P indicating programmed knowledge, and Q conveying questioning insight. Without discarding the importance of P, Revans emphasised the significance of Q in any learning process of addressing real-world problems. Moreover, Revans (2011) were mindful of distinguishing between the notion of puzzles and problems. Puzzles have presumably one correct solution and can be solved with the help of a specialist and are therefore not responsive to action learning. Contrary, problems are amendable to action learning since no single or optimal solution exists (Coughlan and Coghlan, 2010).

Revans (1971) stipulates that the science of action learning comprises the three cyclical and intertwined systems of alpha, beta, and gamma. System alpha concerns framing and investigating a problem, and system beta concerns solving a problem by applying the scientific method (as outlined in section 2.3.1.). In contrast, system gamma focuses on the participants' mindset and monitoring of learning. System Gamma can also be understood as practising critical reflection (Cunliffe, 2004; Høyrup, 2004). Critical reflection includes challenging our fundamental cognitive learning and problem-solving processes, becoming aware of our contextual presuppositions in which the problem is located, and moving beyond focusing on them immediately and whitout observable knowledge about a particular problem (Reynolds, 1998; Choo *et al.,* 2015; Cho and Linderman, 2018).

# 3 Research design

## *3.1 Research context*

The action learning intervention and research occur at VELUX's first production site located in the Western part of Denmark. The VELUX Group is a Danish roof-top window manufacturer founded in 1941 and built on the simple idea of "transforming unused dark attics into bright liveable spaces filled with daylight and fresh air". The distinctive name is a combination of 'VE,' short for ventilation, and 'LUX,' Latin for light – VELUX. Today VELUX is an international company employing 11,500 people with 27 production sites in 10 countries and sales companies in 40 countries.

At VELUX's first production site we find five factories reporting to the same management: aluminium flashing production, aluminium cladding production, wood component production, panes production, and windows assembly.

This paper accounts for action learning intervention following a new attempt to implement IIoT technology after training the leaders as learning facilitators. The management ambition is that the IIoT technology will allow the shop-floor workers to monitor the overall status of the operation through real-time indicators of operating conditions as a foundation for preventive maintenance, proactive repair, and learning-based problem-solving. The insider action research described in this paper occurs in the aluminium cladding, flashing and panes factories.

## *3.2 Research approach*

Since this study both seeks to solve a concrete problem at VELUX and contribute with new theoretical knowledge to the operation management research community it requires a research method that is transdisciplinary, diversified, socially accountable, reflexive, and created in the context of the application, as Gibbons et al. (1994) suggested. Moreover, it requires a method not rooted in the expertise of isolated individuals functioning from a top-down expert model (Gustavsen, 2003). This study, therefore, adopts Action Research (AR), which has been accepted as a valid operation management research methodology for generating actionable knowledge (Coghlan, 2002, 2007), which can be defined as knowledge that is useful to both the academic and practitioner communities (Westbrook, 1993; Chakravorthy and Hales, 2008; Ross *et al.,* 2007; Prybutok and Ramasesh, 2005; Baker and Vaidyanathan, 2012; Coughlan and Coughlan, 2002; Powell and Coughlan, 2020).

More specifically, this study applies insider action research (IAR), which has proven advantageous for practitioner doctorates for contributing to practice, academia, and developing themselves (Coghlan, 2007). Moreover, IAR encourages executives to grow as reflective practitioners and participate in research (Jarvis, 1999; Coghlan, 2004). System improvement, organisational learning, change management, and other organizational concerns are appropriate subjects for IAR because: (1) they are real events that must be managed in real-time, (2) they provide opportunities for both effective action and learning, and (3) they can contribute to the development of theory of what really happens in organisations. Insider action research has its own set of dynamics that set it apart from the work of an external researcher. The researchers are already entrenched in the organisation and have gained knowledge of it as participants in the investigation procedures. This information is achieved through the actor's participation in real-life experiential learning cycles of experiencing, reflecting, conceptualising, and experimenting (Coghlan, 2007). IAR initiatives have also aided in creating collaborative research models in which external academics and insider practitioners collaborate on matters of mutual concern and interest to produce information that fulfils the needs of both communities (Adler *et al.,* 2004; Shani *et al.,* 2008).

### *3.2.1 Research quality and rigour*

IAR builds on an epistemological assumption that academic research not only concerns describing, understanding and explaining the world but also fostering change (Coughlan and Coghlan, 2002; Eden and Huxham, 1996). IAR can directly investigate complex social events, like adopting I4.0 technologies on the shop floor, following the process of constructing and creating the meaning of the participant's environment as they seek to change their organisation (Coghlan and Brannick 2014). IAR is used to generate data and facilitate the creation of actionable knowledge in the context of this study and is, therefore, useful to obtain the purpose of this study. Positivist science criteria should not be used to assess action-oriented research methodologies (Coghlan and Brannick, 2014). Instead, Levin (2003) suggests four criteria for judging the quality of AR, which we believe this study reflects:

1. **Participation:** This study reflects strong cooperation between the researcher and the members of VELUX.
2. **Real-life problem:** The intervention is guided VELUX's challange to adopt and utilise IIoT systems - a concern in real life, with a need for practical outcomes and is governed by constant and iterative reflection as part of the process.
3. **Workable solution:** The insider action research projects are resulting in significant work and sustainable outcomes.
4. **Joint meaning construction** This study reflects an ongoing learning process about reflecting on and interpreting events, articulating meaning and generating

an understanding as a collaborative process between the researcher and the organisational members at VELUX. Specifically, Mezirow's (1990) three forms of reflection are applied within the intervention as it is considered helpful in an action research context and form a meta cycle of inquiry (Coghlan and Brannick 2014): **(1) Content reflection**: the researchers, co-workers and associates think about the issues and about *what* is happening. **(2) Process reflection:** the actors think about strategies, procedures and *how* things are being done. **(3) Premise reflection:** Underlying assumptions and perspectives are scrutinised and address *why* things are happening.

### *3.3 Data collection*

Data collection is an integrated part of the IAR intervention, where data is captured as the participants' learning process unfolds and subsequently fed back to them for evaluation, analysis, reflection, and planning of the following actions with the researcher, leading to further data gathering and so on (Coghlan and Brannick, 2014).

Data were collected in formal and informal settings using different methods, as listed in table I. In addition to reflections on the conducted research, we kept a reflective journal for data collection of observations and informal conversations with the participants (McNiff and Whitehead, 2010).

Table I: Data collection

*Insert Table I*

All of the interviews were done as free-flowing audio-recorded dialogues and accompanied by reflective notes. The goal of the group sessions was to gain more in-depth insights into the participants' opinions as a supplement to the individual interviews. The synergetic discourse among the participants resulted in the generation of different and explicit viewpoints that would otherwise be unavailable (Ryan *et al.,* 2014).

### *3.4 Data analysis*

We adopted Braun and Clarke's (2006, p.87) six-step thematic analysis guide to code the observational and interview data to analyse and find its meaning: (1) First, we familiarized ourselves with the gathered data, (2) then we generated the initial codes, (3) followed by searching for themes, and (4) reviewing these, before (5) the making the final naming and definition of the themes. Finally (6), we produced the report. We used a theoretical theme analysis (Braun and Clarke, 2006), acknowledging that our research influenced our theoretical framework for establishing a learning-to-learn capability, as summarised in sections 2.3.1 to 2.3.4. The thematic analysis helped us understand how the action learning intervention influenced the participants' cognition and behaviour and the outcomes during the development of a learning-to-learn capability. The thematic analysis coding tree (figure 3) is located in section 5.

## 4 The action-learning initiative: Developing a learning-to-learn capability

### *4.1 Diagnosing failed attempt to utilise IIoT systems*

For the case company to understand the effects and challenges of adopting new IIoT technology, the first author followed the implementation of a new IIoT system on one of its cladding department's production lines (Saabye *et al.,* 2020). The acquired IIoT system visually displayed current OEE (Overall equipment effectiveness) and Pareto analysis of unplanned stops in real-time at the shop-floor workers' workstations. The management had created a business case stating that the shop-floor workers would use the displayed real-time data the new IIoT system provided to foster insight for improvements and initiate daily problem-solving activities. Moreover, the business case stated that the project would improve performance, leading to a quick return on investment (ROI). However, six months after commission, production performance had not improved. Moreover, the shop-floor workers had not begun to initiate daily problem-solving activities based on insights generated from the data provided by the IIoT system (Saabye *et al.,* 2020). Diagnosing why the case company was not capable of utilising the IIoT system to improve performance revealed the following findings:

- The shop-floor workers did not recognise it as their job to initiate problem-solving activities independently and regarded this as a job for maintenance, managers, or specialists. Moreover, they perceived the IIoT system as coercive and installed to serve management, not them (Adler and Borys, 1996). In addition, the case company has continually been collecting production performance data and calculating OEE manually. However, the shop-floor workers have never experienced anyone using the data to improve.
- We observed an absence of learning based problem solving on the expence of a practice best characterised as firefighting (Tucker *et al.,* 2002). According to both leaders and managers, they habitually leap over most steps in the scientific method (Liker, 2020; Smith, 1997) when solving problems and go directly into solution mode based on assumptions. This behaviour indicated an absence of leaders fostering a supportive learning environment with room for experimentation and reflection (Revans, 1971; Marsick and Watkins, 2003). Moreover, shop-floor workers and managers reported a widespread tendency to start more initiatives and projects than finish.

### *4.2 Action learning intervention design*

An action learning intervention was designed based on Revans' (1971) intertwined alpha, beta, and gamma learning systems to counter the organisational challenges uncovered during the diagnosis phase. In addition, to make the intervention tangible for the participants, it was supplemented by Rother's (2010, p.155) coaching routines (The five questions) of asking the same foundational set of insightful questions in every coaching cycle. The questions are illustrated in figure 1.

*Insert Figure 1*

Figure 1: The coaching routine questions (Rother, 2021 p.155)

The action learning intervention aims to develop the managers' ability to enable and empower shop-floor workers to practice the scientific method and utilise digital production data when solving problems by fostering a supportive learning environment (Leyer *et al.,* 2018; Liker, 2020).

#### *4.2.1 Organising for learning*

As depicted in figure 2, the design of the action learning intervention constitutes an organisational learning scaffold (Sproull, 2010; Kokkonen, 2014) in the form of a hierarchical coaching structure organised around four distinct roles and three simultaneously interconnected action learning processes. Initially, the shop floor workers assume the learner roles, and the managers undertake the different coach roles, depending on their place in the hierarchy. Finally, the action learning facilitator collaborates with the general manager to assume the third coach role.

*Insert Figure 2*

Figure 2: The action learning intervention (Reprinted from Saabye and Powell, 2021, p.71)

The action learning intervention takes place on the shop floor and has three to four weeks of daily coaching cycles supported by the facilitator. Subsequently, the learners and coaches continue without facilitator support until a problem has been solved, often with less frequent weekly coaching cycles. Afterwards, the shop floor workers and managers are encouraged to apply the improvement and coaching routines on a new problem.

Before involving the shop-floor workers in the action-learning intervention, the first author prepared the managers for learning-based problem solving and coaching (Saabye *et al.,* 2022). Secondly, the purpose is to develop the ability to use a coaching routine to develop others in solving problems by following the scientific method (Ravans, 1971; Shook, 2008; Rother, 2010).

As the action learning intervention evolves and gets deployed across the case company, the participants will shift roles, e.g., senior shop-floor workers, specialists, and project managers will become coaches, and department managers will become second coaches.

#### *4.2.2 Learning to find, face, and frame problems using data (System alpha)*

The first learning process concerns developing the learner's ability to find, face and frame a specific operational problem and design the specific objectives for their problem-solving efforts (Revans, 1971; Ballé *et al.,* 2017). The coach facilitates a content reflection (Mezirow, 1990) by applying the coaching routine (figure 1) to help the learners frame a specific operational problem they are motivated to solve, which can help improve production performance (step 1 in figure 2). An additional learning objective is for the learners to utilise either available digital data or conduct experiments using IIoT systems to generate valuable insights for framing a problem.

#### *4.2.3 Learning to apply the scientific method and learning routines for using data (System Beta)*

The second learning process focuses on process reflection (Mezirow, 1990) and concerns developing the learner's ability to understand and apply the scientific method using IIoT data to solve the identified specific operational problem and future problems.

After framing the specific operational problem, the action learning (AL) groups meet every morning for 15 minutes of coaching (step 1 in figure 2). Grounded on Rother's (2010) coaching routine, the AL groups start each coaching conversation by visualising the problem's current situation and goal with facts, using an action learning board as depicted in Plate 1.

*Insert Plate 1*

Plate 1: The action learning board

Then, to foster insights into the AL group's problem, the coach facilitates a premise reflection (Mezirow, 1990) on their last experiment as knowledge input to define the next small experiment to be conducted until the next day's meeting. The AL groups are encouraged to decide between two types of experiments. Either gather facts or test specific hypotheses. The AL groups are encouraged to utilise either available

IIoT data or conduct experiments using the IIoT systems to generate valuable insights and validate the experiments for both types of experiments. Should the AL groups, e.g., lack the ability to retrieve or analyse data, the next-day step is to learn this ability. The groups use a learning board (Plate 1) and an action and learning log to capture the gained learning and insight.

#### *4.2.4 Learning to critically reflect and develop leadership behaviours supporting learning (System Gamma)*

The third action learning process focuses on developing the coaches by developing their ability to learn how to learn (Revans, 1971). They learn how to become aware of any preconceptions, mental models, and leadership behaviours that hinder the groups from applying the scientific method and solving the problems using IIoT systems to generate valuable insights (Reynolds, 1998; Reason and Torbert, 2001).

After the daily conversation between the coach and the AL groups, the second coach engaged in a process reflection with the coach (Mezirow, 1990). The second coach also applies Rother's (2010) coaching routine to facilitate this reflection process of how the learners are progressing in understanding and applying the scientific method and generating insight from data (step 2 in figure 2). Like the learners, the coach is asked to reflect on her last step and define the following experiment to improve the learners' learning process.

The third coach observes both conversations (Steps 1 and 2 in figure 2). Afterwards, the third coach (the first authour in this study) engages in premise reflection (Mezirow, 1990; Reason and Torbert, 2001) with the second coach on developing the coaches' thinking and practice to develop the AL group's scientific method abilities (step 3 in figure 2). The third coach also applies the coaching routine (figure 1) in the conversation to institutionalise the hieratical coaching structure.

### *4.3 Instigating the action learning initiative*

The initiative emerged into three action cycles that constituted an organisational scaffolding learning process. Table II shows the three action cycles' setup and the operational outcomes.

Table II: Overview of action learning cycles and outcomes

*Insert Table II*

#### *4.3.1 Action cycle 1: learning-to-learn*

The first action cycle aims to test and pilot the action learning intervention in the aluminium component factory. It demonstrates its effect on developing a supportive learning environment empowering the shop-floor workers to find, face, frame, and solve problems independently using the scientific method enabled by the three intertwined learning processes and the hierarchal coaching structure (figure 2). In the first action cycle, digital data was not visible at the workstations, nor had shop-floor workers been instructed how to retrieve the data from the IT systems.

#### *4.3.2 Action cycle 2: learning-to-learn using real-time data*

Besides testing the action learning intervention in another area, the panes factory, the additional focus on the second action cycle was developing the shop-floor workers' ability to foster insights and value creation from real-time data. As a result, the shop-floor workers were provided access to real-time operational data on screens at their workstations, preceding the second action cycle.

#### *4.3.3 Action cycle 3: learning to learn, generating real-time data, and helping others to learn (to learn)*

In the third action cycle, the focus was on empowering the shop-floor workers to decide the types and placement of IIoT sensors on their production lines. For that reason, selected senior shop-floor workers, maintenance specialists, and leaders piloted an IIoT training program consisting of 4 hours of classroom training and a half-day simulation game. Moreover, the third action cycle focused on developing senior shop-floor workers, who already demonstrated informal leadership towards their peers, to take on the role of coaches. Therefore, the action learning facilitator prepared these senior shop-floor workers to assume the role of coaches.

## 5 Findings

In this section, we reflect on the insights emerging through our thematic analysis, as illustrated in Figure 3, of how the participants from VELUX perceived the action learning intervention as instrumental in developing a learning-to-learn capability that enables shop-floor workers to foster insights and improvements from real-time data. Second, we narrate the emergent learning and insights among the participants from VELUX as it unfolds throughout the three action learning cycles.

*Insert Figure 3*

Figure 3: The thematic analysis' coding tree

### 5.1 Insight generated from the thematic analysis

#### 5.1.1 Enabling

System alpha concerns finding, facing, and framing the real problems within the organisation (Revans, 1971). The responses from the participants indicate that the action learning intervention firstly empowered and enabled the shop-floor workers to be the ones who are framing the problems and deciding on what steps to take, "Before it was the highest-ranking person who took the decision, now it is often the shop-floor workers."

Our findings also indicate that the framing of problems involves utilising data, e.g. generated by IIoT systems, "We have learned how to collect and generate useful data and through analysis fostering insights that help us solve our problems". Moreover, the findings indicate that the action learning intervention positively affected the work on the shop floor.

#### 5.1.2 Learning-based problem solving

Adapting to a new way of solving problems requires acknowledging that the existing approach proves inadequate. In this case, both the leaders and shop-floor workers became aware that their approach most of the time resembled firefighting by discarding the problem framing phase a going directly into solution mode; as one of the shop-floor workers reflected, "Before, we also had many data. Still, we did not know how to use them, so we leapt over a lot of the problem-solving steps and went directly into solution mode, often by all speaking at once".

System beta is understood as applying a scientific and learning-based method to solve problems (Revans, 1971), the action learning intervention facilitated that the leaders and shop-floor workers began to use facts, e.g., data generated by the IIoT systems, to conduct small daily steps and experiments until a problem is solved, “Before we tried to make giant steps, now we make small ones”.

### *5.1.3 Supportive learning environment*

Fundamental to a learning-to-learn capability is the presence of a supportive learning environment, which firstly requires leaders proactively acting as learning facilitators, who, e.g., ask questions instead of giving answers and ensure time for conducting experiments and reflections (Saabye *et al.,* 2020).

This requires a long-term learning focus, as one of the leaders responded, “We are sacrificing efficiency in the short term for improving on the long term “. When adopting this mindset, the leaders discovered that it gave them more energy and time, “Now I use coaching every day. It provides value to me since it makes the shop-floor workers experiment and reflect, which gives me more time. The shop-floor workers have responded positively to coaching and want more of it. This also motivates me”.

The above account indicates that the leaders facilitate some of the central elements within system gamma of (critically) reflecting on learning and actions (Revans 1971).

## *5.2 Learning emerging throughout the action learning cycles*

A core emerging actionable knowledge suggests that the three action cycles could be understood as consecutive building blocks for developing a learning-to-learn capability that enables shop-floor workers to foster insights and improvements from real-time data, as depicted in Figure 4.

*Insert Figure 4*

Figure 4: Three consecutive building blocks for developing a learning-to-learn capability enabling real-time data utilisation among shop-floor workers

### *5.2.1 Action cycle 1: learning to learn*

The participating shop-floor workers and leaders reflected a positive attitude towards the new instituted approach to solving problems. As stated by a department manager, "I can see that this way of working motivates the shop-floor workers, since it helps them obtain a better workday". As a contributing factor, the department manager moreover pointed out that the daily routines of only conducting one small step at a time to learn why or why not an experiment had worked as anticipated. Similar opinions were present among the shop-floor workers. As one expressed it, "the process has helped us work more efficiently with optimisations," and another, "We now have less frustration at work. We now have more openness, and we articulate problems together". Moreover, another shop-floor worker reported that they now find it easier to solve their problems independently in the group than waiting for maintenance.

Another department manager had, in addition, experienced that the shop-floor workers have become more proactive, "they now bring forward alternative ideas for solution and problems to work on, which has not happened before. The shop-floor workers have learned that they can solve problems independently".

Despite being a difficult skill to master, the department managers identified their new coaching routines as a significant driver, "the coaching creates ownership for the shop-floor workers' own ideas". Similarly, the factory manager's coaching of the department managers was perceived as central to the positive outcomes. According to the factory manager, the department managers are now more critically reflective of their mental models and behaviours (Reynolds, 1998; Reason and Torbert, 2001; Cunliffe, 2004), leading to a more long-term focus beyond resource efficiency. Moreover, the department managers now take more responsibility for their teams' learning and ask for help and sparring when it becomes difficult.

The department managers also observed teams and departments beginning to collaborate, "the new way of solving problems has improved collaboration between the maintenance specialist, the engineers, and the shop-floor workers". They now discuss together how to solve problems. It has made the shop-floor workers realise that they can engage other colleagues independently". Moreover, the department managers reported that the shop-floor workers began to hold each other accountable in a constructive manner. An observation confirmed by a shop-floor worker who stated, "the best thing about this way of working is that when we have agreed on a next step, you are being held accountable for it. I hope we continue working in this way".

Reflecting on the first action learning cycle with the participants, finding, facing, and eventually frame the first problem to work on for the shop-floor workers is a more challenging learning process than first anticipated for the department managers (Ballé *et al.,* 2017; Wedell-Wedellsborg, 2020). For example, no specific performance gaps to close in one of the AL groups were identified upfront. Therefore, the group defined and initiated no experiments during the first week. The department manager realised that it was not apparent to the shop-floor workers because several performance gaps were apparent to him. He, therefore, conducted a few training sessions where he presented the available performance data and facilitated a process where the shop-floor workers identified a performance gap to start closing. Afterwards, the groups began to identify and execute their first experiments. Another department manager also struggled to help one AL group frame the problem and identify experiments. In this case, the AL group kept eschewing the problem they wanted to be working on and did not reach the conception that they could influence it. Eventually, the department manager dismantled the AL group, and the shop-floor workers were either assigned to one of the other groups or left the action learning intervention. The department managers realised that they must also carefully consider what personalities participate in the AL groups.

A shortcoming of the first action cycle was that the shop-floor workers did not significantly improve their ability to utilise digital production data. Although countless production performance data is being gathered and stored digitally, data was not visible at the workstations, nor were the shop-floor workers instructed on how to retrieve the data from the IT systems.

### *5.2.2 Action cycle 2: learning-to-learn using real-time data*

The second action learning cycle generated similar effects in empowering and developing shop-floor workers to solve problems independently. One shop-floor worker stated, "before our manager told us what to do, now we are the ones deciding on the next step". The shop-floor workers from the second action learning cycle also believe that conducting small daily experiments is something everyone understands and perceives as enabling (Adler and Borys, 1996). One shop-floor worker also highlighted the use of facts and structured experiments as an outcome, "now we write down the goal and current state based on facts instead of assumptions. This is a significant change. Now more shop-floor workers are actively involved in problem-solving and sharing knowledge, leading to improved process flows and less waste". Furthermore, the shop-floor workers express greater attention to communicating and collaborating with their colleagues and the importance of getting different perspectives before deciding on how to solve a problem. According to the participating department manager in the second action cycle, the shop-floor worker has also begun to collaborate directly with other departments when, e.g., implementing new products on their production lines without his support.

The department manager also observes a positive effect on the mood and business understanding, "not even one has mentioned anything negatively, and there seems to be less frustration among the shop-floor workers when they encounter a problem". In addition, the department manager has noticed that the shop-floor workers now use words like 'next steps', 'small steps' and 'mistakes are good' in their daily dialogue with each other.

He also attributes the sense of empowerment among the shop-floor workers to solve problems and make decisions independently to him starting to ask questions and avoiding proposing solutions. Hence the factory's capability to solve problems and handle changes has significantly improved. Another contributing factor to this change is the general manager's shift from following up on key production performance figures to focusing on learning outcomes and reflections (Masick and Watkins, 2003). According to the factory manager, the department managers act less defensive, apologetic, and short-term focused when sharing their department's status, "they now have a longer-term focus on developing a learning-to-learn capability development". As one department manager stated, "the General Manager has made it ok to ask stupid questions".

Reflecting on the effects of the new data screens on generating new insights, several shop-floor workers responded positively. It has provided them with transparency of how their production lines are performing, information only the managers had before (Adler and Broys, 1996). One shop-floor worker stated. "the digital data screens have provided us with a deeper understanding and knowledge about where to intervene." Another shop-floor worker responded, “data can help us save much time in the processes". Moreover, the department managers noticed that shop-floor workers had begun to focus on data validity, "they have proactively and independently initiated making new standards for registering unplanned stops". He also noticed they were asking to see the overall performance figures to confirm the effects of their experimentations, indicating a shift from a coercive to an enabling perception of these figures (Adler and Borys, 1996).

To counter the identified challenges of problem framing from the first action learning cycles, the department manager facilitated a process with the operator based on the available data to determine which performance gaps to address. In addition, the new data screens at the workstations provided insights to frame the problems to work on more quickly. However, it was still facilitated by the department manager and based on predefined data. Hence the shop-floor workers were not involved in deciding where and what to measure on their production lines.

#### *5.2.3 Action cycle 3: learning to learn, generating real-time data - and helping others to learn (to learn)*

The shop-floor workers, specialists and leaders reported that the IIoT pilot training program provided them with an understanding of how to apply IIoT systems and its potential for improving production performance. In addition, the participants highlighted that the half-day simulation game, where they could play and experiment with IIoT sensors and data analyses, gave them the motivation and spirit to apply the technology back on their production lines. During the training, several shop-floor workers openly reflected on where they could put up sensors on their production line.

Subsequently, the shop-floor workers were actively involved with the specialist to identify where to set up the IIoT sensors and create the meeting structure for defining actions on the data with maintenance specialists. "I now facilitate a meeting three times a week where I with colleagues from the shop floor and the maintenance department analyse the data and make decisions for improvement, without the involvement of leaders."

Furthermore, the game made the participants realise how important communication and teamwork are between shop-floor workers and specialists. "I have learned the importance of communication to ensure that everyone has the same understanding of the problem we are trying to solve", as one of the senior shop-floor workers reflected.

Reflecting together with the senior shop-floor workers, who transitioned into the role of first coaches, revealed several insights. Like many leaders, they realised how difficult it is to refrain from stepping into the expert role and providing the answers. To counter this, two of the coaches switched teams. In this way, they were coaching teams on production lines unfamiliar to them, which helped empower the other shop-floor workers to make decisions themselves. For another of the senior shop floor workers, the new coaching role was instrumental in onboarding a team of new employees hired due to significant growth for VELUX.

At the end of this study, the department managers also initiated AL groups outside the formal action learning intervention and reported weekly at meetings with senior management.

## 6 Discussion

According to the study's emerging actionable knowledge, achieving I4.0 and lean complementarity can be defined as a cognitive and behavioural transformation. As a result, manufacturers must rethink how to implement and use IIoT technologies. Manufacturers should focus on building a learning-to-learn capability (Powell and Coughlan, 2020; Saabye *et al.,* 2022) to enable shop-floor workers to foster insights and improvements from real-time data, according to our findings. Therefore, a technocentric and business case approach when implementing the IIoT technology is regarded as ineffective (Leyer *et al.,* 2018; Saabye *et al.,* 2020). To foster insights and improvements from real-time data among shop-floor workers and obtain I4.0 and Lean complementarity, we extrapolate the following proposition in the form of a framework with six conditions, as illustrated in Figure 5.

*Insert Figure 5*

Figure 5: A framework for fostering insights and improvements from real-time data among shop-floor workers.

### *6.1 The underlying conditions for enabling IIoT adoption*

The study reflects that managers' ability to foster a supportive learning environment is the first condition (Balle *et al.,* 2019; Marsick and Watkins, 2003; Choo *et al.,* 2015; Liker and Convis, 2011). This condition is obtained through managers practising a coaching routine of asking insightful and humble questions daily, from the general manager down to the department managers (Rother, 2010; Schein, 2013; Shook, 2008). By asking insightful questions instead of providing answers, the managers create a learning environment where shop-floor workers feel safe to experiment and reflect (Edmonson, 1999). Furthermore, by practising this leadership behaviour to support learning, the managers focus on developing the shop-floor workers to become proficient problems solvers instead of jumping to solutions (firefighting) to resolve specific operational problems (Athur, 1994; Banker *et al.,* 1996; Biazzo and Panizzol, 2000; Tucker *et al.,* 2002; Shook, 2008, Liker. 2020 ).

The second condition for IIoT adoption is to institute new daily learning and problem-solving routines for the shop-floor workers (Johnson *et al.,* 2020). The participants state that the essential elements of the new daily learning and problem-solving routines are framing problems and devising conclusions based on facts, conducting small experiments, and conceiving a set of different ideas and solutions before deciding on a next step or experiment (Ballé *et al.,* 2017; Dean and Snell, 1991; Rother, 2010).

The third condition emerging from this study is to foster an enabling perception among the shop-floor workers of the daily problem solving and learning routines and the IIoT systems (Adler and Broys, 1996). An enabling perception requires the shop-floor workers to experience that both the routines and technology are easy to use and improve their working conditions (Davis, 1989).

The fourth condition concerns providing the shop-floor workers with knowledge on deciding which data to generate. Knowledge is generally reserved for specialists and managers. More specifically, training of shop-floor workers in operating the IIoT technology and setup IIoT sensors as proposed by Ozkan-Ozen and Kazancoglu (2021).

Teaching others is an effective way to learn (Goodlad and Hirst, 1989). Therefore, the fifth condition is to train senior shop-floor workers to take on the coaching role towards their colleagues. Besides improving the senior shop-floor workers' abilities, department managers can activate more AL groups independently by assuming the role of the second coach.

The last condition is the underlying organisational learning scaffold of a hierarchical coaching structure that invokes and connects the other five elements. Moreover, the hierarchical coaching structure ensures an ongoing action learning process of monitoring and improving the other five conditions.

### *6.2 The outcome of the action learning intervention*

After participating in the action learning intervention, the participating shop-floor workers and managers had experienced an effect the ability to generate insights from real-time data and transform them into improvements. Several emergent learnings reflect that the visible real-time data at the workstations provided transparency where their production lines deviated from the current standards (Adler and Borys, 1996). This transparency offered valuable insights into framing problems and evaluating the effects of experiments as an integrated practice of the scientific method (Liker, 2020; Rother, 2010). Moreover, as the IIoT systems became perceived as enabling, increased awareness of data validity emerged, resulting in new standards developed by the shop-floor workers independently for registering data not automatically generated by the IIoT system. In table II, the improvements achieved by the participating AL groups exhibit that IIoT technology combined with a learning-to-learn capability provides improved processes and outcomes. This notion supports Liker (2020) that technology like IIoT systems must be adopted and adapted to help people and processes and not the other way around.

Another reflection emerging from the participants' learning as the three action cycles unfolded was a sense of empowerment among the shop-floor workers to solve problems independently (Leyer *et al.,* 2018; Orgambídez-Ramos and Borrego-Alés, 2014). We observe and report on this empowerment through numerous examples of shop-floor workers leaping their personal development. E.g., taking proactive responsibility for problem-solving activities, making decisions that used to be made by department managers, and driving problem-solving activities instead of a specialist. For example, one shop-floor worker presented the outcome and learning from the first AL group she participated in for the board of directors in a foreign language, something she would not have dreamt of doing before participating in the action learning intervention.

### *6.3 Implication for practitioners*

Rossini *et al.* (2021) suggest that manufacturers should approach lean to achieve a faster and more robust digital transformation, this paper supports a perspective. But how do managers approach lean for undergoing a digital transformation? We suggest developing a learning-to-learn capability to harvest the benefits of I4.0 technologies, like IIoT, through a lean approach. The learning that emerged from the three action cycles presents several specific implications fostering insights and improvements from real-time data among shop-floor workers. Therefore, we recommend, albeit not intended as a rigorous protocol, to follow a phased learning-to-learn capability building approach in conjunction with the deployment of IIoT technology as outlined in Table III.

Table III: A phased learning-to-learn capability building approach for enabling and empowering shop-floor workers to utilise IIoT systems.

*Insert Table III*

## 7 Conclusions

In this 2-year action learning research study, we examined how the case company at VELUX enabled their shop floor workers to generate insights and improvements from IIoT systems. Based on the emergent learning from the three action learning cycles, we demonstrate that adopting and utilising IIoT technologies is not only about developing specific technological capabilities (Machado *et al.,*2021; Saabye *et al.,*2020). It is also about facilitating I4.0 and lean complementarity by developing a learning-to-learn capability through action learning (Powel and Couglan, 2020; Saabye *et al.,*2022).

Moreover, the study demonstrates that the institutionalisation of an organisational learning scaffold (Sproull, 2010; Kokkonen, 2014) in a hierarchical coaching structure is a helpful approach to developing a learning-to-learn capability.

The significant findings of this action learning research study can be summarised as two main conclusions:

(1) A learning-to-learn capability is a fundamental antecedent and enabler for manufacturers to successfully foster insights and improvements from real-time data among shop-floor workers.

(2) When manufacturers seek to adopt I4.0 technologies, complementarity with lean can be enabled by action learning.

Prior research has demonstrated complementarity between I4.0 and lean leading to improved performance and acceleration of a digital transformation (e.g. Buer *et al.*, 2021; Raji *et al.,* 2021; Rossini *et al.,* 2021). But what facilitates this complementarity between I4.0 and lean? We discovered that manufacturers' sole focus on developing technical lean and I4.0 skills proves inadequate for successfully fostering insights and improvements from IIoT systems among shop-floor workers. Instead, it is more effective to think of IIoT utilisation as an emergent action learning process.

From the emerging actionable knowledge generated, we have demonstrated that achieving complementarity between I4.0 and lean can be enabled by action learning. We outline the importance of simultaneously activating system alpha, beta, and gamma (Revans, 1971) to enable shop-floor workers to generate insights and improvements from real-time data. For a learning-to-learn capability system alfa is essential but insufficient since the focus is on addressing a specific problem. System alpha must be intertwined with system beta to develop a learning-to-learn capability enabling the shop-floor workers to solve problems themselves by applying a scientific method

(Smith, 1997). However, to essentially learn to learn, the managers must be able to critically reflect (Cunliffe, 2004; Høyrup, 2004) on the actions and learning derived from the system alpha and system beta activities, which is the purpose of system gamma (Smith, 1997). Hence, institutionalising a hierarchical coaching structure engaging shop-floor workers and all levels of management in the simultaneously learning processes of (a) learning to find, face, frame problems using data, (b) learning to apply the scientific method and learning routines for using data and (c) learning to critically reflect and develop leadership behaviours supporting learning proved effective in developing facilitating I4.0 and lean complemetarity.

### *7.1 Limitations*

A limitation of this action learning research study is the generalizability of the findings since it is a single case study. Conversely, although the learning extrapolated from this research may be particular to the case company's context, it contributes to a generalisable lesson that can inspire practitioners and academics alike. The study can, e.g., encourage practitioners and scholars to develop the socio-technical conditions for fostering insights and improvements from IIoT systems at the shop-floor by harvesting the beneficial effects of deliberately designing action learning interventions on Revan's (1971) system alpha, system beta and system gamma learning processes. We also encourage the research community to consider the potential of contributing to both research and practice stemming from IAR by engaging with practitioner doctorates.

Another limitation concerns the duration of the research. A longitudinal study over two years is a valid length to measure the initial action learning intervention results. However, it takes several years for most manufacturers to fully anchor a new way of working across a whole organisation. Although the study can report that department managers independently deploy the new problem solving and learning routines to more groups, only around a quarter of the shop-floor workers have been exposed to it. Nor is the new IIoT technology dispersed to all departments.

### *7.2 Future research*

With this research, we also intend to draw the attention of the academic and research community affiliated with this journal to become aware of the theoretical possibilities of understanding the phenomenon of I4.0 and lean complementarity for digital transformation through the lens of action learning. We see that the action learning theory offers a valuable application for understanding the underlying socio-technical drivers and barriers when adopting both I4.0 technologies and lean. We, therefore, recommend exploring the use of the study's action learning interventions in various other operations contexts to further our research and examine the validity of our findings. Other factors that explain how people-centric methods foster higher levels of I4.0 adoption could be discovered using qualitative methodologies, e.g. by conducting a quantitative analysis of the conditions presented in this study.

## 8 References

Adler, P.S. and Borys, B. (1996), "Two Types of Bureaucracy: Enabling and Coercive", *Administrative Science Quarterly*, Vol. 41 No. 1, p. 61.

Adler, N., Shani, A.B. (Rami) and Styhre, A. (2004), *Collaborative Research in Organizations*, Sage, Thousand Oaks, CA.

Antony, J., McDermott, O., Powell, D. and Sony, M. (2022), "The evolution and future of lean Six Sigma 4.0", *The TQM Journal*, Vol. ahead-of-print No. ahead-of-print. https://doi.org/10.1108/TQM-04-2022-0135

Arthur, J.B. (1994), "Effects of Human Resource Systems on Manufacturing Performance and Turnover", *Academy of Management Journal*, Vol. 37 No. 3, pp. 670–687.

Baker, T. and Jayaraman, V. (2012), "Managing information and supplies inventory operations in a manufacturing environment. Part 1: An action research study", *International Journal of Production Research*, Vol. 50 No. 6, pp. 1666–1681.

Balci, G. (2021), "Digitalization in container shipping: Do perception and satisfaction regarding digital products in a non-technology industry affect overall customer loyalty?", *Technological Forecasting and Social Change*, Vol. 172, p. 121016.

Ballé, M., Chaize, J. and Jones, D. (2019), "Lean as a learning system: What do organizations need to do to get the transformational benefits from Toyota's method?", *Development and Learning in Organizations: An International Journal*, Vol. 33 No. 3, pp. 1–4.

Ballé, M., Jones, D.T., Chaize, J. and Fiume, O. (2017), *The Lean Strategy: Using Lean to Create Competitive Advantage, Unleash Innovation, and Deliver Sustainable Growth*, 1 Edition., McGraw-Hill Education, New York.

Banker, R.D., Field, J.M., Schroeder, R.G. and Sintia, K.K. (1996), "Impact of Work Teams on Manufacturing Performance: A Longitudinal Field Study", *Academy of Management Journal*, Vol. 39 No. 4, pp. 867–890.

Bi, Z., Jin, Y., Maropoulos, P., Zhang, W.-J. and Wang, L. (2021), "Internet of things (IoT) and big data analytics (BDA) for digital manufacturing (DM)", *International Journal of Production Research*, pp. 1–18.

Biazzo, S. and Panizzolo, R. (2000), "The assessment of work organization in lean production: the relevance of the worker's perspective", *Integrated Manufacturing Systems*, Vol. 11 No. 1, pp. 6–15.

Bittencourt, V.L., Alves, A.C. and Leão, C.P. (2021), "Industry 4.0 triggered by Lean Thinking: insights from a systematic literature review", *International Journal of Production Research*, Vol. 59 No. 5, pp. 1496–1510.

Boyes, H., Hallaq, B., Cunningham, J. and Watson, T. (2018), "The industrial internet of things (IIoT): An analysis framework", *Computers in Industry*, Vol. 101, pp. 1–12.

Braun, V. and Clarke, V. (2006), "Using thematic analysis in psychology", *Qualitative Research in Psychology*, Vol. 3 No. 2, pp. 77–101.

Brown, S. and Vondráček, P. (2013), "Implementing time-based manufacturing practices in pharmaceutical preparation manufacturers", *Production Planning & Control*, Vol. 24 No. 1, pp. 28–46.

Buer, S.-V., Semini, M., Strandhagen, J.O. and Sgarbossa, F. (2021), "The complementary effect of lean manufacturing and digitalisation on operational performance", *International Journal of Production Research*, Vol. 59 No. 7, pp. 1976–1992.

Buer, S.-V., Strandhagen, J.O. and Chan, F.T.S. (2018), "The link between Industry 4.0 and lean manufacturing: mapping current research and establishing a research agenda", *International Journal of Production Research*, Vol. 56 No. 8, pp. 2924–2940.

Cagliano, R., Canterino, F., Longoni, A. and Bartezzaghi, E. (2019), "The interplay between smart manufacturing technologies and work organization: The role of technological complexity", *International Journal of Operations & Production Management*, Vol. 39 No. 6/7/8, pp. 913–934.

Camuffo, A. (2017), *Lean Transformations for Small and Medium Enterprises: Lessons Learned from Italian Businesses*, CRC Press/Taylor & Francis Group, Boca Raton, FL.

Chakravorty, S.S. and Hales, D.N. (2008), "The evolution of manufacturing cells: An action research study", *European Journal of Operational Research*, Vol. 188 No. 1, pp. 153–168.

Chiarini, A. and Kumar, M. (2020), "Lean Six Sigma and Industry 4.0 integration for Operational Excellence: evidence from Italian manufacturing companies", *Production Planning & Control*, pp. 1–18.

Cho, Y.S. and Linderman, K. (2019), "Metacognition-based process improvement practices", *International Journal of Production Economics*, Vol. 211, pp. 132–144.

Choo, A.S., Nag, R. and Xia, Y. (2015), “The role of executive problem solving in knowledge accumulation and manufacturing improvements”, *Journal of Operations Management*, Vol. 36 No. 1, pp. 63–74.
Ciano, M.P., Dallasega, P., Orzes, G. and Rossi, T. (2021), “One-to-one relationships between Industry 4.0 technologies and Lean Production techniques: a multiple case study”, *International Journal of Production Research*, Vol. 59 No. 5, pp. 1386–1410.
Coghlan, D. (2004), ‘‘Managers as learners and researchers’’, in Coghlan, D., Dromgoole, T., Joynt, P. and Sorensen, P. (Eds), *Managers Learning in Action: Management Learning, Research and Education*, Routledge, London, pp. 183-9.
Coghlan, D. (2007), “Insider action research: opportunities and challenges”, edited by MacIntosh, R. *Management Research News*, Vol. 30 No. 5, pp. 335–343.
Coghlan, D. and Brannick, T. (2014), *Doing Action Research in Your Own Organization*, 4th edition., SAGE Publications, Los Angeles [i.e. Thousand Oaks, Calif.].
Coughlan, P. and Coghlan, D. (2002), “Action research for operations management”, *International Journal of Operations & Production Management*, Vol. 22 No. 2, pp. 220–240.
Coghlan, D. and Coughlan, P. (2010), “Notes toward a philosophy of action learning research”, *Action Learning: Research and Practice*, Vol. 7 No. 2, pp. 193–203.
Cunliffe, A.L. (2004), “On Becoming a Critically Reflexive Practitioner”, *Journal of Management Education*, Vol. 28 No. 4, pp. 407–426.
Davis, F.D. (1989), “Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology”, *MIS Quarterly*, Vol. 13 No. 3, p. 319.
Dean, J.W. and Snell, S.A. (1991), “Integrated Manufacturing and Job Design: Moderating Effects of Organizational Inertia”, *Academy of Management Journal*, Vol. 34 No. 4, pp. 776–804.
Demeter, K., Losonci, D. and Nagy, J. (2020), “Road to digital manufacturing – a longitudinal case-based analysis”, *Journal of Manufacturing Technology Management*, Vol. 32 No. 3, pp. 820–839.
Ding, B., Ferràs Hernández, X. and Agell Jané, N. (2021), “Combining lean and agile manufacturing competitive advantages through Industry 4.0 technologies: an integrative approach”, *Production Planning & Control*, pp. 1–17.
Dixit, A., Jakhar, S.K. and Kumar, P. (2021), “Does lean and sustainable manufacturing lead to Industry 4.0 adoption: The mediating role of ambidextrous innovation capabilities”, *Technological Forecasting and Social Change*, p. 121328.
Eden, C. and Huxham, C. (1996), “Action Research for Management Research”, *British Journal of Management*, Vol. 7 No. 1, pp. 75–86.
Edmondson, A. (1999), “Psychological Safety and Learning Behavior in Work Teams”, *Administrative Science Quarterly*, Vol. 44 No. 2, p. 350.
Edmondson, A. and Moingeon, B. (1998), “From Organizational Learning to the Learning Organization”, *Management Learning*, Vol. 29 No. 1, pp. 5–20.
Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P. and Trow, M. (1994), *The New Production of Knowledge*, Sage, London.
Goodlad, S. and Hirst, B. (1989), *Peer Tutoring: A Guide to Learning by Teaching*, Kogan Page, London.
Gustavsen, B. (2003), ‘‘New forms of knowledge production and the role of action research’’, *Action Research*, Vol. 1, pp. 153-64.
Høyrup, S. (2004), “Reflection as a core process in organisational learning”, *Journal of Workplace Learning*, Vol. 16 No. 8, pp. 442–454.

Jarvis, P. (1999), *The Practitioner-Researcher*, Jossey-Bass, San Francisco, CA.

Johnson, M., Burgess, N. and Sethi, S. (2020), “Temporal pacing of outcomes for improving patient flow: Design science research in a National Health Service hospital”, *Journal of Operations Management*, Vol. 66 No. 1–2, pp. 35–53.

Kokkonen, J. (2014), “Stepping into the emptiness: Scaffolding in organizational transition”, *The Learning Organization*, Vol. 21 No. 3, pp. 193–205.

Leyer, M., Richter, A. and Steinhüser, M. (2018), “‘Power to the workers’: Empowering shop floor workers with worker-centric digital designs”, *International Journal of Operations & Production Management*, Vol. 39 No. 1, pp. 24–42.

Levin, M. (2003), “Action research and the research community”, *Concepts and Transformation*, Vol. 8 No. 3, pp. 275–280.

Liker, J.K. (2020), *The Toyota Way: 14 Principles from the World’s Greatest Manufacturer*, Second edition., McGraw Hill, New York.

Liker, J.K. and Convis, G.L. (2011), *The Toyota Way to Lean Leadership: Achieving and Sustaining Excellence through Leadership Development*, McGraw-Hill, New York.

Liu, M., Yu, F.R., Teng, Y., Leung, V.C.M. and Song, M. (2019), “Performance Optimization for Blockchain-Enabled Industrial Internet of Things (IIoT) Systems: A Deep Reinforcement Learning Approach”, *IEEE Transactions on Industrial Informatics*, Vol. 15 No. 6, pp. 3559–3570.

MacDuffie, J.P. (1997), “The road to ‘root cause’: Shop-floor problem-solving at three auto assembly plants”, *Management Science*, Vol. 43 No. 4, pp. 479–502.

Machado, C.G., Winroth, M., Almström, P., Ericson Öberg, A., Kurdve, M. and AlMashalah, S. (2021), “Digital organisational readiness: experiences from manufacturing companies”, *Journal of Manufacturing Technology Management*, Vol. 32 No. 9, pp. 167–182.

Mackelprang, A.W. and Nair, A. (2010), “Relationship between just-in-time manufacturing practices and performance: A meta-analytic investigation”, *Journal of Operations Management*, Vol. 28 No. 4, pp. 283–302.

Marcon, É., Soliman, M., Gerstlberger, W. and Frank, A.G. (2022), "Sociotechnical factors and Industry 4.0: an integrative perspective for the adoption of smart manufacturing technologies", *Journal of Manufacturing Technology Management*, Vol. 33 No. 2, pp. 259-286

Marodin, G.A. and Saurin, T.A. (2013), “Implementing lean production systems: research areas and opportunities for future studies”, *International Journal of Production Research*, Vol. 51 No. 22, pp. 6663–6680.

Marsick, V.J. and Watkins, K.E. (2003), “Demonstrating the Value of an Organization’s Learning Culture: The Dimensions of the Learning Organization Questionnaire”, *Advances in Developing Human Resources*, Vol. 5 No. 2, pp. 132–151.

McNiff, J. and Whitehead, J. (2010), *You and Your Action Research Project*, 3rd ed., Routledge, London ; New York.

Mezirow, J. (1990), *Fostering Critical Reflection in Adulthood: A Guide to Transformative and Emancipatory Learning*, 1st ed., Jossey-Bass Publishers, San Francisco.

Netland, T.H. and Powell, D.J. (Eds.). (2016), *The Routledge Companion to Lean Management*, Routledge, Taylor & Francis Group, New York.

Oliva, R. (2019), “Intervention as a research strategy”, *Journal of Operations Management*, Vol. 65 No. 7, pp. 710–724.

Orgambídez-Ramos, A. and Borrego-Alés, Y. (2014), "Empowering Employees: Structural Empowerment as Antecedent of Job Satisfaction in University Settings", *Psychological Thought*, Vol. 7 No. 1, pp. 28–36.

Ozkan-Ozen, Y.D. and Kazancoglu, Y. (2022), "Analysing workforce development challenges in the Industry 4.0", *International Journal of Manpower*, Vol. 43 No. 2, pp. 310-333.

Powell, D., Morgan, R. and Howe, G. (2021), "Lean First … then Digitalize: A Standard Approach for Industry 4.0 Implementation in SMEs", in Dolgui, A., Bernard, A., Lemoine, D., von Cieminski, G. and Romero, D. (Eds.), *Advances in Production Management Systems. Artificial Intelligence for Sustainable and Resilient Production Systems*, Springer International Publishing, Cham, pp. 31–39.

Powell, D. and Reke, E. (2019), "No Lean Without Learning: Rethinking Lean Production as a Learning System", in Ameri, F., Stecke, K.E., von Cieminski, G. and Kiritsis, D. (Eds.), *Advances in Production Management Systems. Production Management for the Factory of the Future*, Vol. 566, Springer International Publishing, Cham, pp. 62–68.

Powell, D.J. and Coughlan, P. (2020), "Rethinking lean supplier development as a learning system", *International Journal of Operations & Production Management*, Vol. 40 No. 7/8, pp. 921–943.

Prybutok, V.R. and Ramasesh, R. (2005), "An action-research based instrument for monitoring continuous quality improvement", *European Journal of Operational Research*, Vol. 166 No. 2, pp. 293–309.

Raji, I.O., Shevtshenko, E., Rossi, T. and Strozzi, F. (2021), "Industry 4.0 technologies as enablers of lean and agile supply chain strategies: an exploratory investigation", *The International Journal of Logistics Management*, Vol. 32 No. 4, pp. 1150–1189.

Reason, P. and Torbert, W. (2001), "The action turn: Toward a transformational *social* science", *Concepts and Transformation*, Vol. 6 No. 1, pp. 1–37.

Revans, R. (2011), *ABC of Action Learning*, Gower Publishing Limited, England .

Revans, R.W. (1971), *Developing Effective Managers. A New Approach to Business Education*, Longman, London.

Revans, R.W. (1982), *The Origins and Growths of Action Learning*, Studentlitteratur; Goch: Bratt Inst. für Neues Lernen [usw.], Lund.

Reynolds, M. (1998), "Reflection and Critical Reflection in Management Learning", *Management Learning*, Vol. 29 No. 2, pp. 183–200.

Rosin, F., Forget, P., Lamouri, S. and Pellerin, R. (2020), "Impacts of Industry 4.0 technologies on Lean principles", *International Journal of Production Research*, Vol. 58 No. 6, pp. 1644–1661.

Ross, A., Jayaraman, V. and Robinson, P. (2007), "Optimizing 3PL service delivery using a cost-to-serve and action research framework", *International Journal of Production Research*, Vol. 45 No. 1, pp. 83–101.

Rossini, M., Cifone, F.D., Kassem, B., Costa, F. and Portioli-Staudacher, A. (2021), "Being lean: how to shape digital transformation in the manufacturing sector", *Journal of Manufacturing Technology Management*, Vol. 32 No. 9, pp. 239–259.

Rother, M. (2010), *Toyota Kata: Managing People for Improvement, Adaptiveness, and Superior Results*, McGraw Hill, New York.

Ryan, K.E., Gandha, T., Culbertson, M.J. and Carlson, C. (2014), "Focus Group Evidence: Implications for Design and Analysis", *American Journal of Evaluation*, Vol. 35 No. 3, pp. 328–345.

Saabye, H., Kristensen, T.B. and Wæhrens, B.V. (2020), "Real-Time Data Utilization Barriers to Improving Production Performance: An In-depth Case Study Linking Lean Management and Industry 4.0 from a Learning Organization Perspective", *Sustainability*, Vol. 12 No. 21, p. 8757.

Saabye, H., Kristensen, T.B. and Wæhrens, B.V. (2022), "Developing a learning-to-learn capability: insights on conditions for Industry 4.0 adoption", *International Journal of Operations & Production Management*, Vol. 42 No. 13, pp. 25–53.

Saabye, H. and Powell, D.J. (2021), "Fostering Insights from Real-Time Data", in Powell, D.J., Alfnes, E., Holmemo, M.D.Q. and Reke, E. (Eds.), *Learning in the Digital Era*, Vol. 610, Springer International Publishing, Cham, pp. 68–76.

Schein, E.H. (2013), *Humble Inquiry: The Gentle Art of Asking Instead of Telling*, Berrett-Koehler Publishers, Inc, San Francisco.

Shet, S.V. and Pereira, V. (2021), "Proposed managerial competencies for Industry 4.0 – Implications for social sustainability", *Technological Forecasting and Social Change*, Vol. 173, p. 121080.

Shook, J. (2008), *Managing to Learn: Using the A3 Management Process to Solve Problems, Gain Agreement, Mentor and Lead*, Version 1.0., Lean Enterprise Institute, Cambridge, MA.

Smith, P.A.C. (1997), "Performance learning", *Management Decision*, Vol. 35 No. 10, pp. 721–730.

Sousa-Zomer, T.T., Neely, A. and Martinez, V. (2020), "Digital transforming capability and performance: a microfoundational perspective", *International Journal of Operations & Production Management*, Vol. 40 No. 7/8, pp. 1095–1128.

Sproull, L. (2010), "Chapter 4 Organizational learning", in Bird Schoonhoven, C. and Dobbin, F. (Eds.), *Stanford's Organization Theory Renaissance, 1970–2000*, Vol. 28, Emerald Group Publishing Limited, pp. 59–69.

Tortorella, G.L., Cawley Vergara, A.M., Garza-Reyes, J.A. and Sawhney, R. (2020), "Organizational learning paths based upon industry 4.0 adoption: An empirical study with Brazilian manufacturers", *International Journal of Production Economics*, Vol. 219, pp. 284–294.

Tortorella, G.L., Giglio, R. and van Dun, D.H. (2019), "Industry 4.0 adoption as a moderator of the impact of lean production practices on operational performance improvement", *International Journal of Operations & Production Management*, Vol. 39 No. 6/7/8, pp. 860–886.

Tucker, A.L., Edmondson, A.C. and Spear, S. (2002), "When problem solving prevents organisational learning", *Journal of Organizational Change Management*, Vol. 15 No. 2, pp. 122–137.

Verma, A. and Venkatesan, M. (2022), "HR factors for the successful implementation of Industry 4.0: A systematic literature review", *Journal of General Management*, Vol. 47 No. 2, pp. 73–85.

Wagner, T., Herrmann, C. and Thiede, S. (2017), "Industry 4.0 Impacts on Lean Production Systems", *Procedia CIRP*, Vol. 63, pp. 125–131.

Wedell-Wedellsborg, T. (2020), *What's Your Problem? To Solve Your Toughest Problems, Change the Problems You Solve*, Harvard Business Review Press, Boston.

Westbrook, R. (1993), "Orderbook models for priority management: A taxonomy of data structures", *Journal of Operations Management*, Vol. 11 No. 2, pp. 123–142.

Womack, J.P., Jones, D.T. and Roos, D. (1991), *The Machine That Changed the World: How Japan's Secret Weapon in the Global Auto Wars Will Revolutionize Western Industry*, 1st HarperPerennial ed., HarperPerennial, New York, NY.

Yilmaz, A., Dora, M., Hezarkhani, B. and Kumar, M. (2021), "Lean and industry 4.0: Mapping determinants and barriers from a social, environmental, and operational perspective", *Technological Forecasting and Social Change*, p. 121320.

Yoo, W.-J., Choo, H. and Lee, S. (2018), "A Study on the Sustainable Growth of SMEs: The Mediating Role of Organizational Metacognition", *Sustainability*, Vol. 10 No. 8, p. 2829.

Zelbst, P.J., Green, K.W., Sower, V.E. and Bond, P.L. (2019), "The impact of RFID, IIoT, and Blockchain technologies on supply chain transparency", *Journal of Manufacturing Technology Management*, Vol. 31 No. 3, pp. 441–457.

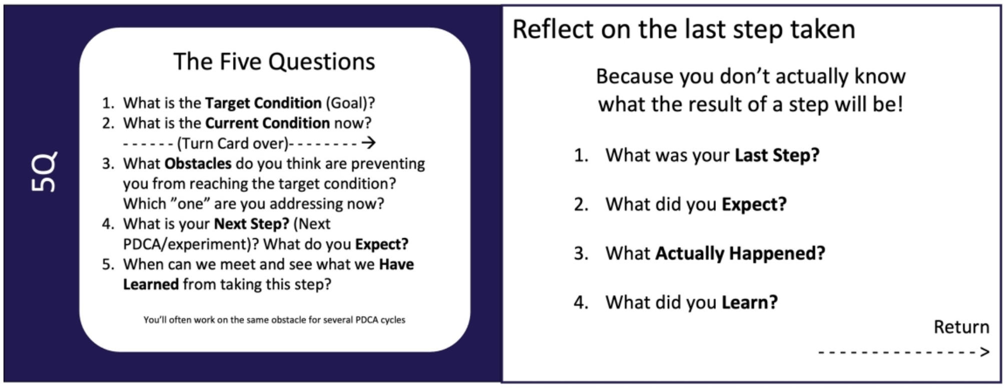


Figure 1: The coaching routine questions (Rother, 2021 p.155)

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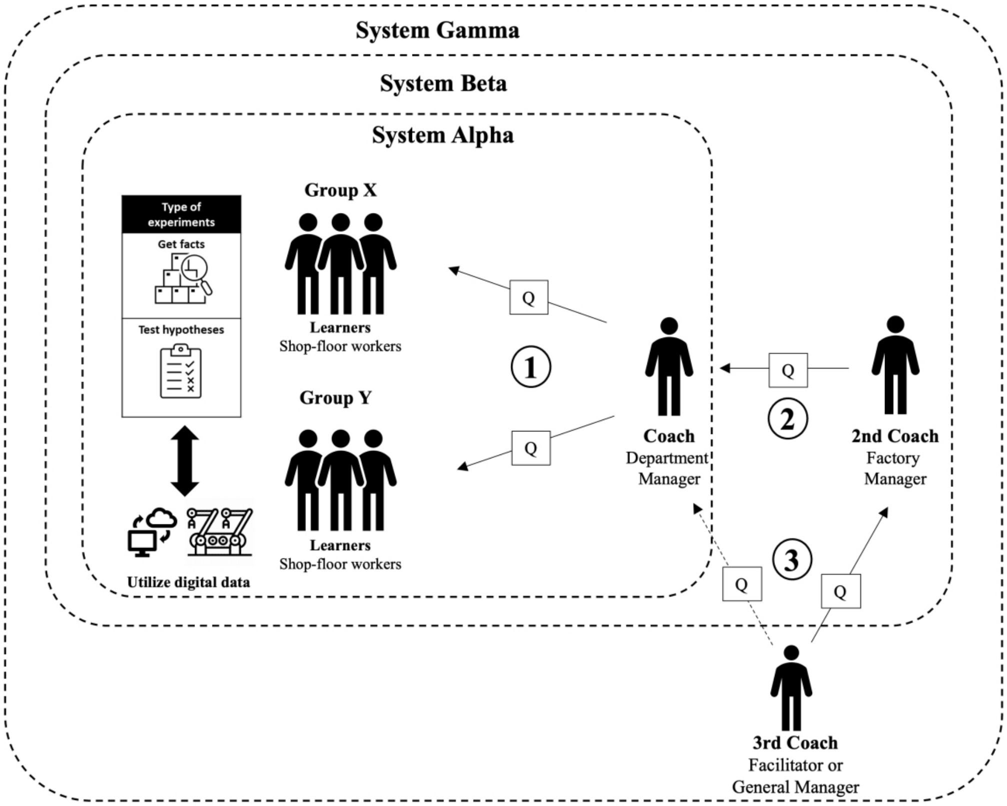


Figure 2: The action learning intervention (Reprinted from Saabye and Powell, 2021, p.71)

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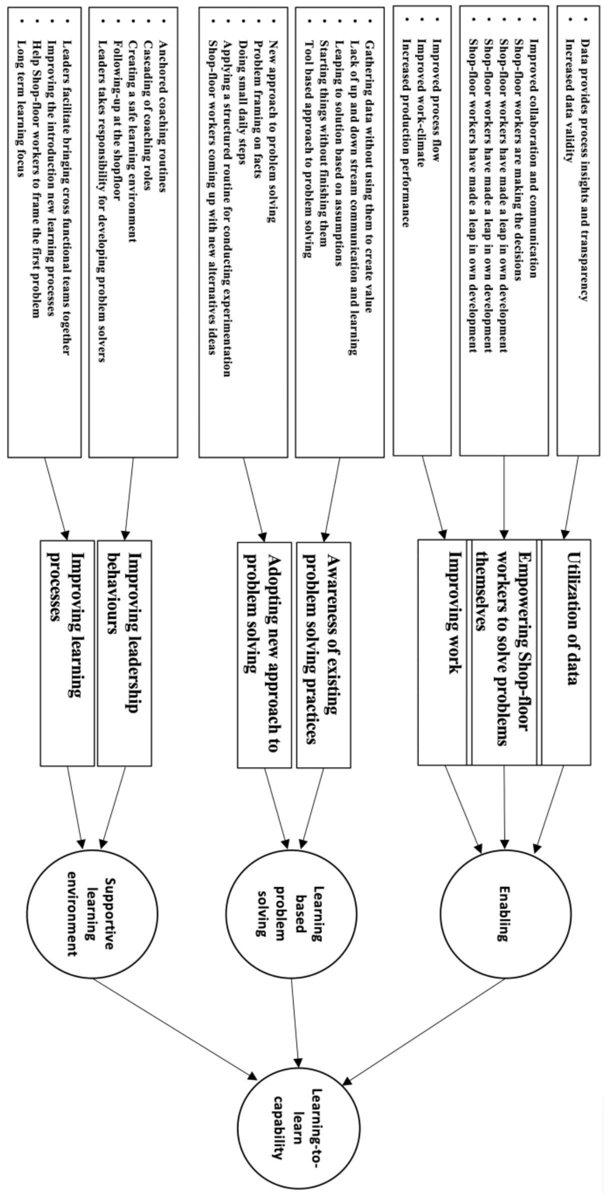


Figure 3: The thematic analysis' coding tree

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Figure 4: Three consecutive building blocks for developing a learning-to-learn capability enabling real-time data utilisation among shop-floor workers

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Figure 5: A framework for fostering insights and improvements from real-time data among shop-floor workers.

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| Collection method | Data source | Data type |
|---|---|---|
| **Participant observation** | • 13 Action Learning projects<br>• 91 Coaching cycles (between AL groups and coach)<br>• 73 Coaching cycles (between 1st and 2nd coach)<br>• 36 Dyadic coaching sessions with 2nd coaches (30-45 min)<br>• 4 hrs IIoT classroom training<br>• 5 hrs IIoT simulation game | • Audio recordings<br>• Field and reflective notes |
| **Semi-structured interviews** | • 15 interviews with participants (30-45 min pr. interview)<br>• 13 Group learning and evaluation sessions (1 hrs pr. session) | • Audio recordings<br>• Field and reflective notes |
| **Archival data** | • 13 Learning (problem-solving) presentations<br>• 20 Actions and learning logs<br>• Operational production line performance data | • Problem-solving sheets<br>• Excel sheets with performance data |

| Action cycle | Data technology | Leaning focus | Action learning groups | Participants | Problem | Outcome |
|---|---|---|---|---|---|---|
| 1. Learning to learn | Operators have access to data, but must be retrieved by specialist<br><br>Data defined by specialist. | Develop shop-floor workers ability to find, face, frame and solve problems by understanding and following the scientific method<br><br>Develop managers to fostering a supportive learning environment by institutionalize a hieratical coaching structure. | Group 1.1<br>(Cladding production) | 3 shop-floor workers<br>1 department manager<br>1 factory manager<br>1 maintenance manager | Reduce changeover time and number of heavy lifts | Changeover time reduce and number of heavy lifts reduced with 50%. |
| | | | Group 1.2<br>(Cladding production) | 3 shop-floor workers<br>1 maintenance manager<br>1 department manager<br>1 factory manager | Reduce lead time | No effect and discontinued before time due to no motivation and engagement among participating shopfloor workers. |
| | | | Group 1.3<br>(Flashing production) | 12 shop-floor workers<br>1 quality specialist<br>1 maintenance manager<br>1 department manager<br>1 factory manager | Reduce unplanned stops, standardize work and roles | Improved productivity of 11% |
| | | | Group 1.4<br>(Cladding production) | 2 shop-floor workers<br>1 quality specialist<br>1 maintenance manager<br>1 department manager<br>1 factory manager | Reduce unplanned stops | Two major cause of unplanned stops eliminated = 2% improved productivity |
| | | | Group 1.5<br>(Flashing production) | 6 shop-floor workers<br>1 quality specialist<br>1 maintenance manager<br>1 department manager<br>1 factory manager | Reduce workload by improving workflow and collaboration between groups | Percentage point from employee survey:<br>- Workload: -4<br>- Collaboration: +12<br>- Nearest leader: +16 |
| | | | Group 1.6<br>(Cladding production) | 2 shop-floor workers<br>1 quality specialist<br>1 maintenance manager<br>1 department manager<br>1 factory manager | Reduce number of defects materials from supplier | OEE from 45 to 60 |
| 2. Learning to learn using digital data | Operators have access to data on screens at workstation.<br><br>Data defined by specialist | Develop shop-floor workers ability foster insights and value creation from real-time data. | Group 2.1<br>(Panes production – track 7) | 3 shop-floor workers<br>1 quality specialist<br>1 maintenance specialists<br>1 department manager<br>1 factory manager | Reduce changeover time and number of heavy lifts | Improved productivity of 8% |
| | | | Group 2.2<br>(Panes Packaging) | 5 shop-floor workers<br>1 quality specialist<br>1 quality manager<br>1 department manager<br>1 factory manager | Reduce lead time | Improved productivity of 12% |
| | | | Group 2.3<br>(Panes Hardening) | 4 shop-floor workers<br>1 quality specialist<br>1 department manager<br>1 factory manager | Reduce unplanned stops, standardize work and roles | Improved productivity of 10% |
| | | | Group 2.4<br>(Panes Production - Track 6) | 1 shop-floor workers<br>1 quality specialist<br>1 quality manager<br>1 department manager<br>1 factory manager | Reduce quality issues | Reduction in unplanned stops and improved quality |
| 3. Operators learning other operators to learn defining and using data | Operators have access to data on screens at workstation.<br><br>Operators involved in defining data. | Develop shop-floor workers to decide the types and placement of IIoT sensors.<br><br>Develop senior shop-floor workers to take on the role as coaches. | Group 3.1<br>(Panes Hardening) | 3 shop-floor workers<br>1 quality specialist<br>1 maintenance specialists<br>1 department manager | Reduce unplanned stops | Reduction in unplanned stops with from 70 to 10 times |
| | | | Group 3.2<br>(Panes production – track 7) | 3 shop-floor workers<br>1 quality specialist<br>1 maintenance specialists<br>1 department manager | Reduce unplanned stops | Improve production output with 10% |
| | | | Group 3.3<br>(Flashing production) | 10 shop-floor workers<br>1 quality specialist<br>1 maintenance manager<br>2 maintenance specialists<br>1 department manager<br>1 factory manager | Reduce unplanned stops | Reduction in unplanned stops with 50% |

| Step | Activity | Description | Reference |
|---|---|---|---|
| 1 | Prepare the managers | Develop the managers' ability to solve problems themselves and use the coaching routine (see figure 1) for developing others in solving problems by following the scientific method (see section 2.3.1). Central to this training is for the managers to shift focus from addressing the problem itself to the underlying problem framing and solving process, also referred to as critical reflection. | Figure 1; Section 2.3.1, 4.4.2 |
| 2 | Identify participants and problems | Managers appoint the shop-floor workers that are committed to learning, for the first AL groups and facilitate the initial process of finding, facing, and framing a problem based on available data (see section 4.4.2). | Figure 1; Section 2.3.1, 4.4.2 |
| 3 | Initiate daily learning and problem-solving routines | Managers introduce and initiate the daily learning and problem-solving routines with the AL groups. By practising the coaching routine (see figure 1) the managers develop the shop-floor workers' understanding and application of the scientific method (see section 2.3.1). Moreover, the role of the second and third coach is activated as well. Thus, the successful adoption of these outcome-specific learning routines will be cumulative rather than iterative as experiments are conducted and support the social aspects of the change towards a new way of working. | Figure 1, 2, 3; Image 1 Section 2.3.1, 4.3.1 |
| 4 | Foster insights and improvements from real-time data | As the IIoT screens, displaying the real-time data, become present at workstations, the coaches encourage the shop-floor workers to experiment with the generated data. Adopting new technology is an adaptive problem-solving or improvement activity. | Image 2 Section 4.3.2 |
| 5 | Train shop-floor workers in setting up IIoT sensors | Leaders and specialists are likely to become a scarce resource for driving improvements, leaving the shop floor workers with a coercive perception of the IIoT technology and preventing utilisation. Therefore, manufacturers must train and empower shop floor workers to decide where to set up IIoT sensors and what type of data to capture. | Section 4.3.3 |
| 6 | Train shop-floor workers as coaches | To institutionalise and diffuse the learning-to-learn capability across a manufacturing company, shop floor workers must assume the role of first coaches; otherwise, the managers will become a bottleneck in the transformation. | Figure 1, 2; Section 4.3.3 |
| 7 | Diffusing the new way of working | Once the first AL groups successfully have experienced fostering insights and improvements from real-time data, senior management must embark on the difficult journey of ensuring diffusion. Senior management must proactively encourage department managers as second coaches to constantly empower shop floor workers to solve new problems by following the scientific method. | Figure 2, Section 2.3.1 |

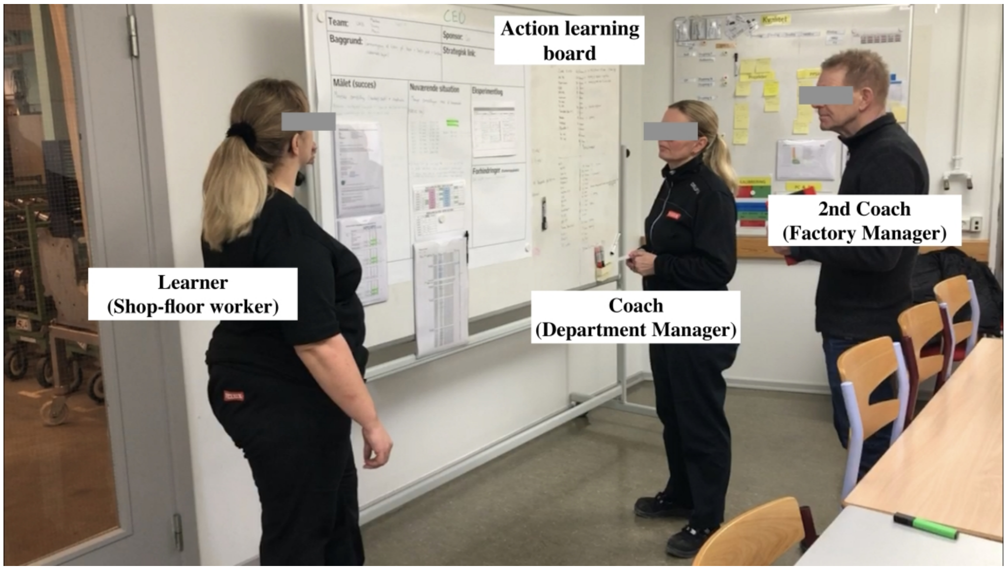


Plate 1: The action learning board

470x264mm (300 x 300 DPI)