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Published in:
International Journal of Operations and Production Management

DOI (link to publication from Publisher):
10.1108/IJOPM-07-2021-0428

Publication date:
2022

Document Version
Publisher's PDF, also known as Version of record

Developing a learning-to-learn capability: insights on conditions for Industry 4.0 adoption

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Received 3 July 2021
Revised 3 November 2021
Accepted 27 November 2021

Abstract

Purpose – This paper investigates how manufacturers can develop a learning-to-learn capability for enabling Industry 4.0 adoption.

Design/methodology/approach – This research design is guided by our research question: How can manufacturers develop a learning-to-learn capability that enables Industry 4.0 adoption? The authors adopt action research to generate actionable knowledge from a two-year-long action learning intervention at the Danish rooftop window manufacturer VELUX.

Findings – Drawing on emergent insights from the action learning intervention, it was found that a learning-to-learn capability based on lean was a core construct and enabler for manufacturers to adopt Industry 4.0 successfully. Institutionalizing an organizational learning scaffold encompassing the intertwined learning processes of systems Alpha, Beta and Gamma served as a significant way to develop a learning-to-learn capability for Industry 4.0 adoption (systematic problem-solving abilities, leaders as learning facilitators, presence of a supportive learning environment and Industry 4.0 knowledge). Moreover, group coaching is a practical action learning intervention for invoking system Gamma and developing leaders to become learning facilitators – an essential leadership role during Industry 4.0 adoption.

Originality/value – The study contributes to theory and practice by adopting action research and action learning to explore learning-to-learn as a core construct for enabling Industry 4.0 adoption and providing a set of conditions for developing a learning-to-learn capability. Furthermore, the study reveals that leaders are required to act as learning facilitators instead of relying on learning about and implementing Industry 4.0 best practices for enabling adoption.

Keywords Industry 4.0, Lean, Action learning, Group coaching, Action research

Paper type Research paper

1. Introduction

Many manufacturers are embarking on digital transformation to maintain or increase competitive advantage by developing organizational capabilities to adopt Industry 4.0 (I4.0) technologies as a significant enabler of business improvements (Dalenogare *et al.*, 2018; Frank *et al.*, 2019; Sousa-Zomer *et al.*, 2020; Tortorella *et al.*, 2019; Warner and Wagner, 2019).

Funding: The research was funded by Innovation Fund Denmark (No: 9065-00123B).

However, the implementation of I4.0 requires both substantial investments and changes in the organizational aspects of the company (Bag *et al.*, 2018; Büchi *et al.*, 2020; Tortorella *et al.*, 2019). Industry-focused studies report 60–85% failure rates of organizational digital transformation initiatives (Bucy *et al.*, 2016; Sailer *et al.*, 2019).

To counter the challenges of digital transformations within operation management, academics and practitioners are investigating how lean can leverage the potential of I4.0 (Buer *et al.*, 2018; Rosin *et al.*, 2020). Chiarini and Kumar (2021) reported that lean serves as a foundation for maximizing the impact of I4.0 technologies. Tortorella *et al.* (2019) reported similar findings. However, they stressed that a technocentric adoption approach toward I4.0 does not improve operational performance. Instead, it is a people-centric change of mindset, behavior, and work practices that constitutes a genuinely lean organization, representing the enabling influence of I4.0 (Cagliano *et al.*, 2019; Marcon *et al.*, 2021). A lean organization is characterized by the presence of an organizational learning-to-learn capability (Powell and Coughlan, 2020). In a lean organization, the leaders are facilitators of learning (Maalouf and Gammelgaard, 2016) who develop and empower employees to autonomously find, face, frame and solve problems together with co-workers to improve operational performance (Ballé *et al.*, 2017; Franken *et al.*, 2021; Mohaghegh and Furlan, 2020).

While the extant operation management literature highlights the importance of a people-centric approach when adopting I4.0 and lean (Cagliano *et al.*, 2019; Marcon *et al.*, 2021), research on the underlying learning processes of how manufacturers can develop the necessary learning-to-learn capabilities to achieve this is scarce (Demeter *et al.*, 2020). Therefore, this paper reports on an action learning project at the Danish rooftop windows manufacturer VELUX aimed at developing the learning-to-learn capabilities for adopting I4.0. Despite being a lean-intensive manufacturer, VELUX has been unsuccessful in improving operational performance by adopting I4.0 technologies (Saabye *et al.*, 2020). VELUX realized through a failed I4.0 technology adoption project that it required the leaders to develop a learning-to-learn capability to acquire I4.0 knowledge, frame I4.0 projects and ensure collaboration across functions within their organization, in a way that moved beyond their current technocentric and cost-cutting approaches.

We adopt Revans' (1971) theory of action and science of praxeology of cyclical systems – Alpha, Beta and Gamma – as a framework for understanding the intricacies of building a learning-to-learn capability. This paper contributes to the operation management literature with a set of conditions necessary for I4.0 adoption:

(1) Organization-wide systematic problem-solving abilities.

(2) Leaders serving as learning facilitators.

(3) Supportive learning environment.

(4) Organizational learning scaffold.

(5) Knowledge about I4.0 technologies and adoption.

These findings are extrapolated by applying an intervention-based action research approach (Coughlan and Coghlan, 2002; Oliva, 2019) to gain insight and expand our understanding of how to develop a learning-to-learn capability (Powell and Coughlan, 2020) by conducting and researching an action learning project at VELUX to answer the following research question:

RQ1. How can manufacturers develop a learning-to-learn capability that enables Industry 4.0 adoption?

The rest of the paper is structured as follows to answer the research question: In the next section, we introduce the challenges of adopting I4.0. We locate the challenge in theory by exploring, contrasting, and synthesizing the lean and learning literature associated with learning-to-learn capabilities. Second, we address this challenge by narrating and discussing the action learning intervention at VELUX. Finally, we extrapolate the theoretical and practical contributions and highlight limitations and future research directions.

2. Theory: locating the challenges

To locate our theoretical lens, we provide an interpretive synthesis of the relevant theories in this section. This review provides a theoretical framework for the observed phenomena under examination, allowing the reader to find and understand the root of the theory-related issue.

2.1 I4.0 adoption challenges

The concept of I4.0 is a new industrial paradigm characterized by a suite of digital technologies (Büchi *et al.*, 2020; Xu *et al.*, 2018). I4.0 is known as smart manufacturing and represents new possibilities for manufacturers to develop intelligent products and processes that enable autonomous data collection and analysis and interaction between products, processes, suppliers, and customers in real time (Buer *et al.*, 2018; Cagliano *et al.*, 2019; Dalenogare *et al.*, 2018). In addition, there is an overall consensus that I4.0 positively impacts value streams by making manufacturing systems more flexible to product changes and more responsive to unexpected events (Tortorella *et al.*, 2019).

Prior I4.0 research has primarily been driven by a focus on technocentric approaches to improve the performance of manufacturers (e.g. Dalenogare *et al.*, 2018) and identifying different maturity and adoption levels for adopting I4.0 technologies (Moeuf *et al.*, 2018; Colli *et al.*, 2019). However, manufacturers that seek to adopt I4.0 technologies without addressing the people-centric elements risk failing to deploy and utilize them (Cagliano *et al.*, 2019; Lassen and Waehrens, 2021). Only recently have studies begun to research the people-centric conditions required for successful implementation of I4.0 (Cagliano *et al.*, 2019; Demeter *et al.*, 2020; Marcon *et al.*, 2021; Tortorella *et al.*, 2019). Tortorella *et al.* (2020) stressed that despite the technology-driven approach implied by I4.0, people-oriented aspects like empowerment of employees and active participation in problem-solving activities will continue to play an essential role in improving operational performance. Similarly, Rosin *et al.* (2020) and Tortorella *et al.* (2019) emphasized that improvement from technology adoption requires alignment between a set of organizational aspects of employees' empowerment, motivation, and capabilities to explore and exploit new technologies.

2.2 Lean as the foundation for adopting I4.0

Extant research studies imply that lean serves as a foundation for successfully adopting I4.0 technologies. According to Rosin *et al.* (2020), I4.0 does not replace lean; instead, manufacturers must pursue the deployment and improvements of lean practices and principles when adopting I4.0. Chiarini and Kumar (2021, p. 14) proposed that lean provides the foundation for maximizing the impact of I4.0 technologies on operational performance, and Demeter *et al.* (2020) identified lean as a necessity during the first stages of I4.0 deployment. However, for lean to serve as a foundation and enabler for adopting I4.0 technologies, sustainable lean implementation is required, which cannot be taken for granted, since a high rate of lean implementation failure exists (Jadhav *et al.*, 2014; Scherrer-Rathje *et al.*, 2009).

2.3 Lean as a learning-to-learn capability

Liker (2020) and Ballé *et al.* (2017) described learning-to-learn as being at the core of lean. Similarly, Hartwell and Roth (2010) suggested that the organizational learning process of setting expectations, trying new approaches, collecting data, making changes, assessing outcomes relative to expectations and adjusting approaches are essential for adopting lean. Hines *et al.* (2004) regarded changes as testing a hypothesis by learning why an experiment was successful or not; hence, a lean organization learns how to learn through improving their ability to conduct experiments.

Learning-to-learn is the core enabler and primary condition for manufacturers building lean capabilities and enabling sustainable improvements (Bessant *et al.*, 2003). To counteract failed implementations, we might rethink lean as a learning system rather than a production system (Powel and Coughlan, 2020; Powell and Reke, 2019). From this perspective, manufacturers must acknowledge the value of employing and developing people with continuous improvement mindsets who are capable of solving operational problems as an instilled routine (Hines *et al.*, 2004; Liker, 2020; Rother, 2010). Effective problem solving is essential for adopting a learning-to-learn capability (Bateman, 2005; Hines *et al.*, 2004; Netland, 2016).

2.3.1 Systematic problem-solving abilities. People (and, indirectly, organizations) learn from solving problems. Problems should therefore be perceived as an opportunity to learn rather than something to avoid (MacDuffie, 1997; Revans, 2011). However, not every problem-solving activity leads to individual (or organizational) learning and increased performance (Argyris, 1976; Tucker *et al.*, 2002). Mohaghegh and Furlan (2020) divided problem solving in organizations into two approaches: intuitive problem solving (IPS) and systematic problem solving (SPS). IPS is characterized by people applying intuitive reasoning with minimal cognitive effort to overcome immediate obstacles by assuming what constitutes the problem, applying short-term fixes and ignoring the underlying root causes. In contrast, the core of SPS is applying analytical reasoning and deliberate cognitive effort to fundamentally solve problems at their root causes and address problems by following the scientific method (Liker, 2020; Mohaghegh and Furlan, 2020; Smith, 1997). In the operations management literature, the scientific method is operationalized by a setup of different tools and methods based on Deming's Plan-Do-Act-Check (PDCA) cycle for continuous improvement. DMAIC (Schroeder *et al.*, 2008), A3 thinking (Shook, 2008), and eight-step problem0solving or Jishuken (Marksberry *et al.*, 2010) are all approaches for SPS-based programs, but they all follow the same set of logically linked stages (Revans, 2011, p. 13):

(1) *Survey*: observation.

(2) *Hypothesis*: theorizing and conjecture.

(3) *Experiment*: practical tests are carried out.

(4) *Contrast*: actual and desired or theoretical results are compared.

(5) *Review*: results are assessed according to the overall objectives and situation.

In the operation management literature, SPS is directly correlated with the quality of solutions and decisions (Baer *et al.*, 2013; Gray, 2001). Researchers recognize SPS as the enabler of strategic capabilities and competitive superiority (Cho and Linderman, 2019; Tucker *et al.*, 2002). However, although manufacturers are implementing programs to develop SPS capabilities as a foundation for lean, many struggle to achieve a satisfying and sustainable outcome over time (Bateman, 2005; Netland, 2016).

2.3.2 Leaders as learning facilitators. Lean requires leaders at all organizational levels to change their own mindset and behavior as well as exhibit commitment and effective communication abilities (Van Dun and Wilderom, 2016; Tortorella *et al.*, 2018). Mann (2009) ascribed only 20 percent of the effort in a lean transformation to implementing practices and tools, and 80% to changing leaders' behaviors. Learning is at the core of lean, and leaders must be facilitators of learning (Maalouf and Gammelgaard, 2016), coaching their employees by challenging their basic assumptions and mental models (Cao *et al.*, 2012; Ellinger and Bostrom, 1999). Moreover, the role of leaders is to foster a supportive learning environment and involve others, so employees develop their problem-solving skills and a more thorough understanding of continuous improvement (Cao *et al.*, 2012; Ellinger and Bostrom, 1999). This implies coaching as a principal practice (Liker, 2020; Powell and Coughlan, 2020; Rother, 2010). Unlike traditional and teacher-centered education, the coaching process supports learners in making their own decisions during a problem-framing process (Britton, 2015). Unfortunately, most leaders struggle to develop a lean mindset and become effective learning facilitators and coaches (Hines *et al.*, 2004; Liker, 2020; Moyano-Fuentes and Sacristán-Díaz, 2012).

2.3.3 Action learning. One of the basic precepts of action learning (AL) is that when the velocity of change exceeds the velocity of learning, you are in trouble—whether as an individual or as an organization (Boshyk and Dilworth, 2010). AL is conceived to cope with this change through learning, and was defined by Revans (2011, p. 24) as "*to make useful progress on the treatment of problems/opportunities where no 'solution' can exist already because different managers, all honest, experienced, and wise, will advocate different courses of action in accordance with their different value systems, their experiences and their different hopes for the future.*" Central to the practice of AL is Revans' (2011, p. 85) statement, "*There can be no learning without action, and no (sober and deliberate) action without learning.*"

Revans (2011) proposed that we needed to flip the "normal" learning process on its head and introduced his learning formula: $L = P + Q$. The L stands for "learning," the P for "programmed knowledge" (traditional classroom or textbook activities), and the Q for "questioning insight" in his learning equation (i.e. question-driven inquiry). The Q factor distinguishes AL from other types of learning, so this is where the process should start. To cope with the velocity of change, he believed that we should place far more emphasis on the Q and less on the P. Rather than rushing to debate alternative solutions, AL begins with the Q – the asking of questions – as opposed to the P, as we have been trained to do in both schools and the workplace.

In the learning formula, Revans (1971) complements AL with the theory of action and science of praxeology of cyclical and intertwined systems of Alpha, Beta and Gamma, which this study considers to be the core conditions of a learning-to-learn capability. System Alpha is understood as the ability to find, face, and frame relevant organizational problems. System Beta concerns how the organizational problem is solved by applying the scientific method. System Gamma concerns the leaders' learning process of better understanding themselves and the organization where they work. The focus is on reflecting on the change of the system the leaders are trying to improve.

Revans (2011) distinguished between what he referred to as puzzles and problems. Puzzles, which supposedly have only one correct answer and can only be solved with the assistance of experts, are not receptive to AL. Problems are amenable to AL since no single or optimal solution exists (Coghlan and Coughlan, 2010). The adoption of I4.0 can be considered a problem. It contrasts the technocentric approach to I.40 adoption, evident in Dalenogara *et al.* (2018) and Frank *et al.* (2019), which has focused on identifying best practices and different maturity and adoption levels for adopting I4.0. This traditional approach conceptualizes the I.40 adoption as a puzzle in AL terms, and from such a perspective, $L = P$.

None of the three systems can stand alone but demand different levels of attention at different times as new I4.0 technology is adopted (Powell and Coughlan, 2020). System Alpha is therefore important to determine which problem an I4.0 project will address. System Beta is essential in ensuring that the project is effectively implemented. Finally, system Gamma is key to ensuring that project sponsors, leaders, and participants critically reflect on their decisions and learning to ensure better outcomes throughout a project's lifetime.

Drawing on literature outside AL research, the practice behind system Gamma is similar to critical reflection (Boshyk and Dilworth, 2010), which is a higher-order thinking process and questions the premises on which a problem has initially been framed. Thus, critical reflection represents understanding and developing our learning and problem-solving processes (Høyrup, 2004; Reason and Torbert, 2001; Swanson, 1990). Critical reflection is synonymous with upstream and downstream learning (Reason and Torbert, 2001). "Upstream" learning refers to challenging the presuppositions underlying our beliefs and the mental models with which we frame problems and solutions. "Downstream" learning refers to adjusting behavior following the insight gained from the upstream learning process. Critical reflection requires a psychologically safe learning environment where one can speak up without risk of punishment or humiliation (Edmonson, 1999).

To facilitate the critical reflective processes within a safe learning environment, group coaching can be applied, since it is difficult in a dyadic coaching setting for the coachee to fully recognize the systemic elements of mental models and their effects on the problem-solving process, for example, which requires third-person participants as observers (Brown and Grant, 2010). Often, mental models that hinder solving ill-defined problems, such as I4.0 adoption, are shared between the organization's members. Challenging them should occur in an interactive learning process among trusted peers (Høyrup, 2004). Therefore, group coaching is an integrated and evidence-based practice that can overcome dyadic coaching's inadequacies to create a shared understanding of the challenges related to I4.0 adoption (Brown and Grant, 2010; Kets de Vries, 2005).

3. Research design

3.1 Research site: VELUX Group's first production subsidiary

The VELUX Group is a Danish roof windows manufacturer founded in 1941 that builds on the simple idea of transforming unused dark attics into bright livable spaces filled with daylight and fresh air. Today, VELUX is an international company employing 11,500 people, with 27 production sites in 10 countries and sales companies in 40 countries. The group AL intervention occurs in Denmark's western part, where VELUX develops its products for the European markets. The production engineering departments are situated next to the company's first production subsidiary, now a supporting lead factory for product and production process development.

Despite being profitable as a manufacturer, the existing application of lean can be characterized primarily as methods-based without supportive lean management behaviors (Camuffo and Gerli, 2018). The lead factory's management has realized that it must further develop its capabilities to support the development of new products and production processes and the future growth of VELUX. This capability development includes engaging in digital transformation to become much better at adopting I4.0 technologies and conducting automation projects for cost-cutting purposes. The lead factory has recognized that the current method-based approach to managing its operations is insufficient (Saabye *et al.*, 2020). Therefore, management initiated the AL intervention and, for synergic purposes, invited the production engineering departments to participate. VELUX agreed to full transparency in reporting on the action research (AR) project as long as no product-related information was communicated.

3.2 The action research approach

The focus of this study is to test and advance our understanding of I4.0 adoption by applying an AL intervention at VELUX (Oliva, 2019). AR is therefore used because the real situation investigated in this study has considerable managerial and practical relevance for

VELUX as well as significant scientific importance for operation management research (Coughlan and Coghlan, 2002). In operations management, AR has been acknowledged as a legitimate study approach for overcoming observational constraints (e.g. Chakravorthy and Hales, 2008; Powell and Coughlan, 2020; Prybutok and Ramasesh, 2005; Westbrook, 1993).

The detailed reporting of fieldwork generated from conducting AR is all too often overlooked, yet crucial to the development of theory (Caniato *et al.*, 2018). First, AR aims to achieve both practical results and the creation of new knowledge in a natural context. AR is research *in* action rather than research *about* action (Coughlan and Coghlan, 2002). Second, AR is an abductive research method that evaluates and refines past theoretical knowledge throughout the intervention. Third, AR is a cyclical and continuing process of planning, acting and assessing results, which leads to further planning (Coughlan and Coghlan, 2002). Fourth, individuals of the investigated organizational system take an active role in the cyclical AR process and are termed co-researchers (Reason and Bradbury, 2008). Fifth, as an external assistance, researchers play an active role in the process, purposefully influencing the system (Coghlan and Brannick, 2014). The researcher's role is to work with management teams to ensure that the learning mechanism is of high quality, as well as to take the lead in making sense, structuring theoretical contributions, and explaining and communicating emerging insights (Coughlan and Coghlan, 2002). Our research design can be characterized as a two-year longitudinal embedded single case study, whereby the three AR cycles of the study comprise the embedded cases (Yin, 2018).

3.3 Data collection

Data collection is an integral element of the AR intervention, with data being collected on the participants' learning progress and then sent back to them for assessment, analysis, reflection, and planning of the next steps with the researcher, leading to more data collection, and so on (Coghlan and Brannick, 2014). The analysis for the study includes the senior executives, senior leaders, department managers, project managers, and specialists, as listed in Table 1. The first AR cycles follow the learning processes of the executive sponsors, and the second cycle follows the learning processes of the senior leaders. The third AR cycle, which is divided into four AL subgroups, follows the learning processes of the project leaders, department managers and specialist.

Data was gathered utilizing a variety of approaches in both formal and informal settings, as outlined in Table 2. Besides 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). We conducted all interviews as free-flowing dialogues and audio-recorded them together with reflective notes. As a supplement to the individual interviews, the group interviews' purpose was to get more in-depth insights into the participants' perspectives. The participants' synergetic dialogue generated additional explicit views that would otherwise be less accessible (Ryan *et al.*, 2014).

3.4 Data analysis

To analyze and make sense of the observational and interview data, we applied Braun and Clarke's (2006, p. 87) six-step thematic analysis, as illustrated in Table 3. Specifically, we performed a theoretical thematic analysis (Braun and Clarke, 2006), acknowledging that our study was driven by our theoretical frame about developing a learning-to-learn capability based on Revans' (1971) intertwined systems of Alpha, Beta and Gamma. The thematic analysis helped us make sense of how the AL intervention affected both the participants and outcomes during the development of a learning-to-learn capability.

Action learning cycle	Role	Tenure	Age	Span of control	Education level
1	General manager	54	45	400	Master
	Director	14	39	14	Master
	HR manager	26	57	0	Bachelor
	Lean manager	4	39	35	Master
	Director	40	66	12	Crafts training
	Director	26	59	12	Bachelor
2	Factory manager	30	63	7	Crafts training
	Factory manager	18	43		Bachelor
	Factory manager	16	43	55	Master
	Director	25	58	13	Master
	Technical manager	2	38		Academy professional
	Portfolio manager	5	30	6	Master
3.1	Project manager	4	31		Master
	Project manager	2	45		Master
	Specialist	14	52		Crafts training
	Specialist	9	35		Crafts training
	Project manager	4	31		Master
	Department manager	5	31	84	Master
	Specialist	14	35		Upper secondary education
	Department manager	3	29		AP
3.2	Specialist	21	55		Crafts training
	Department manager	33	57	51	Primary school
	Project manager	4	30		Master
	Specialist	28	54		Crafts training
	Specialist	21	50		AP
	Specialist	30	56		Crafts training
	Specialist	30	57		Crafts training
3.3	Department manager	11	35	55	Primary school
	Department manager	22	42	89	Upper secondary education
	Project manager	3	30		Master
	Specialist	6	56		Academy professional
	Specialist	4	44		Master
3.4	Specialist	14	39		Master
	Specialist	3	29		Master
	Specialist	26	45		Academy professional
	Project manager	10	37		Master
	Specialist	8	56		Academy professional
	Specialist	22	54		Master
	Specialist	26	57		Academy professional

Table 1.
List of participants and unit of analysis

3.5 Research quality and rigor
AR has been criticized in the literature for its lack of repeatability (Eden and Huxham, 1996) and the researchers' participation (Coughlan and Coghlan, 2002). However, when evaluating action-oriented research techniques, positivist scientific standards should not be employed (Coghlan and Brannick, 2014). Instead, as Coghlan and Shani (2014) argued, AR should be judged on its rigor, reflection, and relevance. The research quality of this study is based on the following criteria (Karlsson, 2016, p. 257):

Table 2. Data collection

Collection method	Data source	Data type
Participant observation	• 4 Industry 4.0 simulation games • 3 IoT pilot projects • 25 group coaching sessions (4–5 h p. Session) • 63 group coaching cycles • 53 dyadic coaching sessions with sponsors (30–45 min p. Session)	• Audio recordings • Field and reflective notes
Semi-structured interviews	• 41 learning and evaluations interviews of the group coaching intervention (1 h p. Interview) • 6 group learning and evaluation sessions (2 h p. Session) • 5 follow-up interviews with participants (45 min p. Interview)	• Audio recordings • Field and reflective notes
Archival data	• 41 problem-solving presentation • 41 Written evaluations (questionnaire) • Operational production line performance data • Strategy and project reports	• PowerPoint presentations • A3 problem solving sheets • Excel sheets with performance data • Online survey tool

(1) The purpose and rationale for the core action and research, as described in the pre-step, are firmly established to form the basis of the intended contribution to both situation-specific theory and practice.

(2) The operational, organizational and academic context of the research is chosen.

(3) The methodology and methods of inquiry define the roles played by the researchers and how they make contact with the organization and identify ethical issues.

(4) The design of data collection and generation methods informs how cycles of action and reflection are planned and how collaborative relationships are built.

(5) The narrative of events is described, including intended and unintended outcomes.

(6) Reflection on and analysis of the narrative (or story) is undertaken in the light of experience gained, judgments made and the theory.

(7) The discussion extrapolates to a broader context and articulates the proposed contributions to both situation-specific theory and practice.

3.5.1 Balancing the role duality of the organizational and research role. The first author is employed by VELUX and subsidized by the Danish Innovation Fund as an industrial PhD fellow and insider action researcher (Coghlan, 2019) to develop and facilitate the AL intervention. As with any insider action researcher, one of the strengths is the easy access to data, although role duality is a challenge to be conscious of. To balance this role duality, the first author, as researcher, returned to the affiliated university to discuss and reflect with academic colleagues. This was also to ensure validity of data and to avoid research bias (Van da Ven, 2007).

When assuming the role of facilitator within VELUX, the first author adopted the three facilitating roles of an AL advisor (Pedler and Abbot, 2013, pp. 27–32). The first role is the AL designer (accoucheur). This role involves introducing AL to the organization, ensuring sponsorship among senior executives and, together with them, designing the AL program. The second role is the action learning group facilitator, which involves facilitating the AL

Steps	Procedural comments
1. Familiarizing yourself with your data: Transcribing data (if necessary), reading and re-reading the data, noting down initial ideas	As we went through the data, excerpts and related meta-data were entered into an Excel sheet as quotes and translated from Danish to English. The translation process served as a helpful way to become immersed and familiar with the collected data. Ideas and labels for coding were noted into the Excel sheet
2. Generating initial codes: Coding interesting features of the data in a systematic fashion across the entire data set, collating data relevant to each code	Based on the organized data stored in our Excel sheet, we performed open coding by assigning meaningful codes to the translated quotes in the form of short sentences (e.g. "before, peers came with solutions instead of asking questions"). During this iterative process, we started to identify commonalities and patterns and align the codes' phrasing where it made sense, mainly in a theory-driven approach. We occasionally went back to our observational and interview notes to extract quotes that were initially discarded and added these to our analysis
3. Searching for themes: Collating codes into potential themes, gathering all data relevant to each potential theme	Once the first round of first-order codes was done, we conducted an axial coding to group these into a higher level of category candidates, followed by the last selective coding of theme candidates. The second and third-order codes were labeled with short states (e.g. safe learning environment, problem-framing ability). Similar to the previous step, we occasionally went back to our observational and interview notes to extract quotes that were initially discarded and added these to our analysis. During this iterative process of aligning the categories, we used visual representations in PowerPoint to aid us in sorting the different codes into categories and themes
4. Reviewing themes: Checking if the themes work in relation to the coded extracts (level 1) and the entire data set (level 2), generating a thematic "map" of the analysis	As we reviewed the themes and their underlying codes and excerpts, it became evident that some were not themes, some were divided into two, and some were collapsed with others. Based on this process, a thematic map was created and validated to represent our data set's meaning accurately
5. Defining and naming themes: Ongoing analysis to refine the specifics of each theme and the overall story the analysis tells, generating clear definitions and names for each theme	We arrived at systems Alpha, Beta and Gamma through several iterations of defining and redefining the essence of the themes in relation to the underlying story we wanted to convey in this paper and our theoretical approach to the thematic analysis. Figure 2 (in Section 5) depicts the final analysis
6. Producing the report: The final opportunity for analysis. Selection of vivid, compelling extract examples, final analysis of selected extracts, relating back of the analysis to the research question and literature, producing a scholarly report of the analysis	Following the AR tradition, the focus of the final steps was to tell the story of our data in a convincing way for the merit and validity of our analysis. For this, we engaged the participants/co-researchers from VELUX and academic colleagues to review the report and provide feedback

Source(s): Braun and Clark (2006, p. 87)

Table 3.
Thematic analysis

intervention. As an AL group facilitator, it is important not to act as an authoritative expert, instead striving for self-facilitation of AL. Once AL groups are activated, the third role involves facilitating organizational and professional learning. This means supporting executive sponsors to diffuse the insight gained from organizing change through AL and institutionalization within the existing system. By explicitly adopting an AL advisory role, the first author was able, within the boundaries of AR, to maintain independence as researcher.

4. The action learning initiative of developing a learning-to-learn capability

4.1 Diagnosing failed attempts at adopting I4.0

To understand how proficient VELUX's lead factory was at adopting I4.0 technology, the first author investigated the implementation of a new Internet of Things (IoT) system on one of the factory's production lines. The intention with the IoT system was to provide real-time operational data to the shop-floor workers for them to utilize and improve production performance. Six months after being commissioned, however, production performance had not improved. The shop-floor workers had not performed any problem-solving efforts based on insights provided by the IoT system (Saabye *et al.*, 2020). VELUX recognized from the failed attempt to adopt the IoT technology that the imposed emphasis on improving efficiency by 4% annually institutionalized a sole cost reduction focus when implementing new technology. For example, robots and automation technology were implemented to reduce direct labor and were primarily managed by a small team of specialists and engineers with limited involvement with senior leaders, shop-floor workers, and other functions like logistics and maintenance. This approach proved inadequate when adopting I.40 technologies like IoT and helped VELUX recognize that it first required a learning and leadership change. Projects for adopting I4.0 technologies must be perceived as more than a technical challenge by leaders, which requires transcending from a sole cost reduction focus when exploring and framing I4.0 projects. Moreover, it requires the project teams to engage and collaborate more broadly with shop-floor workers and other employees. The leaders must therefore become active sponsors and facilitators to ensure this transformation.

The diagnosis resulted in the following findings:

(1) From a system Alpha perspective, the responsible leaders and project managers had not invested time in framing the problem they wanted to solve with the IoT technology. Unconsciously, the project was framed as a puzzle of (technically) implementing a new piece of technology by experts. Hence, the project was planned to end once the system was online.

(2) From a system Beta perspective, aided by experts, they leaped into a technocentric solution mode and discarded the scientific method's application. For example, the shop-floor workers, as the primary users of the system, were not involved in the analysis phase. No experiments were conducted to identify the best system from a social-technical perspective. Furthermore, the prevalent approach to problem solving could be characterized as firefighting (Tucker *et al.*, 2002).

(3) From a system Gamma perspective, the diagnosis revealed no visible presence of a supportive learning environment in which shop-floor workers, experts, and managers could collaborate on performing experiments and reflecting on problem-solving efforts and the use of new technologies. The absence of a supportive learning environment also revealed that the leaders were not facilitating learning but providing answers and solutions rather than asking questions and creating a habit of applying the scientific method among their direct subordinates (Liker, 2020; Rother, 2010).

As part of the diagnosis, the lead factory performed an analysis of the project portfolio's performance. The analysis revealed that only 9% of the initiated projects were finalized on time and that only 40% of the initiated projects had been structurally framed.

4.2 Designing the action learning initiative

The organizational problems identified during the diagnostic phase were addressed by developing an AL program based on the foundations of Revans' (1971) intertwined Alpha, Beta, and Gamma learning systems and his (2011, pp. 17–39) key logistics of action learning, as depicted in Figure 1.

The purpose of the AL program is first to gain programmable knowledge (*P*) and awareness about I4.0 technology and related adoption challenges through participating in the I4.0 simulation game. The second purpose is to develop the participants' ability to become learning facilitators who can develop others to practice the scientific method and adopt I4.0 by fostering a supportive learning environment (Liker, 2020; Pendler and Abott, 2013). As illustrated in Figure 1, each AL program consists of two parallel learning tracks as depicted: a sponsor track and a participant track. Once a participant has completed that AL program, they can enroll in the sponsor track with their subordinates as participants. This is to support the goal of establishing self-managed AL (Pedler and Abbott, 2013). Establishing an organizational learning scaffold (Kokkonen, 2014; Sproull, 2010) in the form of a hierarchical coaching structure organized around three distinct roles and three parallel AL processes serves as an enabler for self-managed AL.

Initially, the participants assume the learning role but start to practice the first coach role, both during the group coaching sessions and as part of their actions between sessions. The last role is the one of second coach or learning facilitator, which is the focus of the sponsor track. When a participant or an employee is working on a concrete problem of e.g. adopting I4.0 technology, three parallel AL processes are initiated:

(1) Solving a concrete problem (system Alpha).

(2) Learning how to solve problems (system Beta).

(3) Critically reflecting on and learning how to develop others to solve problems (system Gamma).

As the leaders become proficient within the different roles, the organizational learning scaffold becomes institutionalized.

The program consists of AL activities divided into workshops within the AL group and performing (learning) actions in between. Group coaching sessions are conducted during each workshop and organized in subgroups. Sponsors are obliged to conduct individual coaching sessions with their subordinates on the problem they work on during the program. Shook's (2008) practices of A3 thinking and Rother's (2010) practices of improvement and coaching routines are a formal part of the AL program as concrete supportive practices for participants to adopt. Finally, the program is concluded with an extraction session (constituting the AR reflection element) where a panel of relevant stakeholders and their sponsors participate. At this session, the participants first present the problem they have been trying to solve during the program. More importantly, they also present their learning and reflections from the program, recommendations for improving the program, and how to move forward with anchoring and sustaining the new way of working. A detailed description of the AL intervention is outlined in Table 4.

5. Findings from conducting the action learning initiative

In this paper, we adopted AR to address the research question: How can manufacturers develop a learning-to-learn capability that enables Industry 4.0 adoption? This section first reflects on the rich data and insights generated and frames these reflections in terms of the systems Alpha, Beta and Gamma that emerged from our thematic analysis and are summarized in Figure 2. Second, we reflect on the participants' learnings from the individual AL cycles.

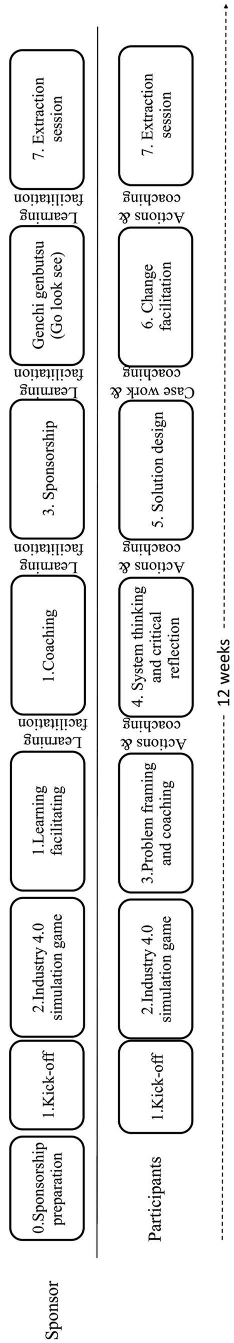

Figure 1.
The action learning intervention

Table 4. Description of the action learning intervention

Phase	Intervention sub-activity	Description
Initiating the AL program intervention	0. Sponsorship preparation	The AL program represents a significant cognitive change for participants. The first step is to ensure active and visible sponsorship from the responsible senior leader, who should lead the organization where the intervention occurs. Next, the sponsor must have a clear understanding of what transformation the AL program can enable. The sponsor must communicate this to the organization, beginning practice, role model critical reflection orientation, and systematic problem-solving practices
	1. Kick off session	A facilitator and the sponsor explain the purpose, learning objectives, and processes behind the AL program. The sponsor and participants exchange their expectations and motivations for engaging in the AL program. In preparation for the first session, the participants read the *Managing to Learn* book (Shook, 2008) and watch short topic-related videos. The book and videos help participants gain practical insight into performing and developing learning-based problem solving among employees
	2. Industry 4.0 simulation game	To help participants become aware of how their current thinking and behaviors create problems when adopting I4.0, they participate in an I4.0 simulation game within a smart production laboratory. The smart production laboratory is a real and physical production setup that acts as a playground for participants to experience how different digital manufacturing technologies work and the organizational challenges when implementing them (see https://move2x.dk/en/new-gameplay-with-velux/). The facilitator conducts other management simulations and role-plays, such as Deming's red bead experiment, throughout the intervention
	Choosing a relevant problem	In addition to the passive learning elements of reading and watching videos, participants must also identify and describe a real-life and relevant strategic problem related to the emergent transformation. They are encouraged to experiment with the Toyota-inspired A3-thinking process to describe their problem (Shook, 2008). It is the role of sponsors to ensure that participants identify a relevant problem to work on
Sponsor track	Session 3–6	The sponsor participates in a series of individual sessions with the AL facilitator and eventually with an executive sponsor. The purpose of these sessions is to prepare the sponsor for the next learning activity that their participants will go through and reflect on their own development and the development of their own participating subordinates. Besides developing themselves as learning facilitators, another outcome from the program is to gain new insights about their subordinates' proficiencies, e.g. to identify and solve problems, and engage, empower and coach others as opposed to firefighting. In each session, a theme is discussed. These themes are (1) learning facilitation (2), coaching (3), sponsorship and (4) *Genchi Genbutsu*, which in English means to go and see the location or process where the problem exists to solve that problem more quickly and efficiently
	Learning facilitation	Between the sessions, the sponsors practice facilitating learning by coaching participants and others, asking insightful questions to foster reflection in all types of meetings, and observing the development of their subordinates

(*continued*)

Phase	Intervention sub-activity	Description
Participants track	Sessions 3–6	A set of cognitive aids is presented at the sessions to support participants' learning through models, short lectures, handouts, and exercises. The purpose of cognitive aids is to support the participants with a common frame of reference. This common frame of reference is associated with participants' learning process of exploring and improving their understanding of coaching, the problem-framing process, the concrete problems they are working on, and their underlying mental models, for example. A curriculum is prepared to address the sessions: (3) problem framing and coaching; (4) system thinking and critical reflection; (5) solution design; and (6) change facilitation
	Group coaching	Group coaching is an essential part of the AL program consisting of one or more group coaching cycles. Each group coaching cycle is a four-step learning process that lasts approximately 45 min. The participants are introduced to a coaching aid based on coaching kata (Rother, 2010). The coaching aid provides participants with a structured routine to follow within every dyadic coaching conversation. In addition to the coaching aid, the participants practice and learn to ask additional critical reflective follow-up questions In the first step, the group assigns the roles of coach and coachee. The rest of the participants constitute a reflective group of observers. A dyadic coaching conversation is the second step, and only the coach and coachee may speak for the first 10–15 min. Meanwhile, the participants observe flawed presuppositions and note down critical reflective questions. In the third step, the group coaching conversation, the observers are first invited to ask their critical reflective questions but refrain from providing solutions. After 10 min, the observers may share some advice and recommendations to help the coachee. In the essential last step of critical reflection, the participants take a step back for 10–15 min to reflect on the group coaching cycle at hand. This critical reflection explores the experiences, observations, and areas for improvement from the coaching conversations, e.g. (1) listening, asking and receiving questions, (2) the problem-framing process, and (3) mental models and presuppositions. Once a group coaching cycle is concluded, the next one can start with other participants assuming the coach and coachee roles
	Actions and coaching	The participants continue working with their problems between each group coaching session by integrating the learnings and insight obtained on the sessions. Between the group coaching sessions, the participants engage in problem framing of their real-life strategic problem. As participants gain more insight into their problems, they often either re-formulate or change the real-life strategic problem. Sponsors are obliged to coach the participants, both to help and develop the participants but also to develop their own coaching skills
	Extraction sessions	To ensure that the learning from the AL program is internalized by participants, an extraction session with their sponsor and relevant stakeholders is conducted. At the extraction sessions the participants (1) present the problem they have been working on during the program, (2) share their reflections, learning and evaluation of the impact and application of the AL program and (3) facilitate a dialogue around the perspectives and opportunities for the organization to apply the practices of the AL program
After action learning intervention	Participants as sponsors	After completing the AL program, the participants switch roles

Table 4.

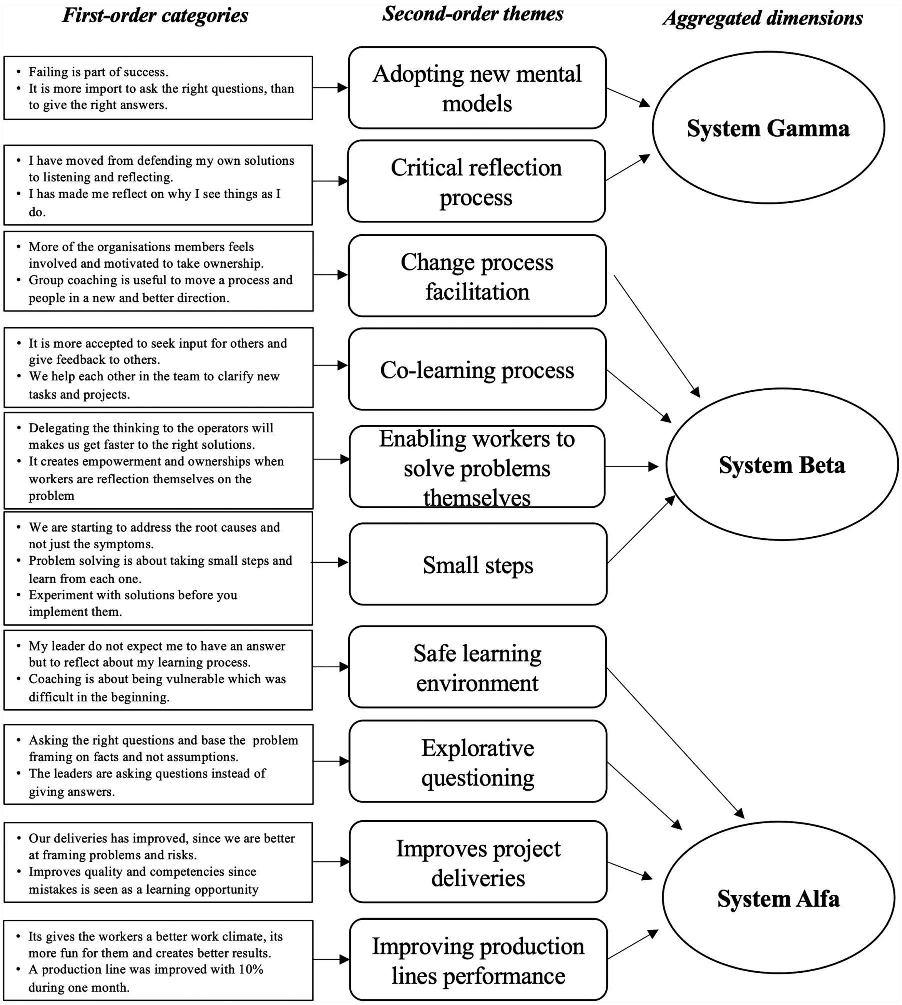

Figure 2.
Thematic analysis

5.1 Insights generated reflecting system Alpha, Beta, and Gamma

5.1.1 System Alpha. Revans (1971) stated that system Alpha concerned finding, facing, and framing a real organizational problem. In this regard, the participants responded that the AL intervention made them frame the problem first (understood as gap between the current and desired state) before thinking about the solution. As one of the specialists reflected,

> Before we started to think about the solution when implementing new technology, now we start thinking about the problem. We now focus on asking the right questions and framing the problem on facts—not assumptions.

5.1.2 System Beta. System Beta concerns applying the scientific method to the problem-solving process through multiple cycles of action and reflection (Revans, 1971). According to participants, the AL intervention provided them with a deeper understanding and proficiency in applying the scientific method when solving problems:

> We are starting to address the root causes and not just the symptoms. Problem solving is about taking small steps and learning from each one, and experimenting with technology and solutions before you implement them.

Several of the participants also highlighted that they now saw the problem-solving process as co-learning and a change process:

> It is more accepted to seek input from others and give feedback to them. We now help each other across departments to clarify new tasks and projects. Group coaching is useful to move a process and people in a new and better direction.

However, participants also reported that it was a struggle to find time to work more in-depth on their cases:

> I feel like I needed more time to immerse myself in the theory, the practical exercises and working on my problem case.

5.1.3 System Gamma. System Gamma concerns critical reflection on the learning as experienced by participants. It involves self-awareness, and questioning underlying mental models and basic assumptions that hinder system Alpha and Beta. Working in system Gamma is the most difficult for participants, since critical reflection is less tangible than analyzing and solving a problem where concrete methods can be applied. In the beginning, most participants' common frustrations and challenges were about receiving questions and acknowledging that these were about fostering reflection and identifying better actions. For example, one of the mental models revised by the respondents was the idea that one must know the answers upfront:

> Before the group coaching intervention, I felt that I needed to come up with the correct answer; it was almost like being in an exam. Now I think that failing is a central part of the process of being successful with a project. Therefore, it is entirely acceptable not to know the answers or make a mistake, as long as I am learning.

Another participant also shared the discomfort of the group coaching sessions in the beginning; however, he embraced the new approach as more group coaching sessions were conducted.

> I was really out of my comfort zone, and not something that I found comfortable. I think I was more focused on the theory and trying to do it satisfactorily than the ability to try to learn. My understanding did improve over time, as I started to see the benefit of the questions. For me, the sessions revealed blind spots not addressed previously about problem I was working on.

Once the organization began to embrace problems as learning and improvement opportunities, the respondents realized that it was more important to ask questions than provide answers, especially when assuming the coach's role. Another common reflection emerging among the participants was related to systemic awareness of anchoring a learning-to-learn capability.

> For this to work, it is not enough that it is only our department that is working in this way.

One of the executive sponsors realized that the new way of thinking needed to be integrated into the existing procedures for project portfolio management and strategy deployment.

5.2 Emergent learnings from the individual action learning cycles

5.2.1 Action learning cycle 1: developing executive sponsors. The executive sponsors' reflections from the first AL action cycle were positive. They expressed that it had provided them with profoundly new perspectives on how to lead change in their organizations and ensure I.40 adoption. A shared response by the executive sponsors was embracing the role of a learning facilitator who focused on developing their organizations to solve the problem themselves through asking insightful questions.

> I have become consciously aware of my own leadership style. I now focus on learning instead of firefighting and problem solving as a mental and reflective process.

To adjust the mental models preventing learning-based problem solving and developing a learning-to-learn capability, the executive sponsors indicated critical reflection as a central underlying process in their transformation.

> I have begun to reflect on why I see things as I do. I have learned how critically examining our existing beliefs and mental models affects our abilities to solve problems and eventually ensure a digital transformation. I now ask myself, "What is the end goal?" and take time-outs to reflect on problems before deciding how to proceed.

As the first AL cycle progressed and more group coaching sessions were conducted, the executive sponsors began to demonstrate a more critical reflective approach to problem solving as they realized they were only practicing it in an intuitive way (Mohaghegh and Furlan, 2020). First, they became mindful of not jumping to conclusions and spent considerably more time understanding and framing a problem by suppressing their assumptions when coaching.

> During the coaching conversation, I can now see that I only had a focus on the technical part and wanted him [the coachee] to find another technical solution without investing in new robots. During the conversation, it did not occur to me that the problem could be different from a technical one.

They realized that they merely were asking questions to close their own knowledge gaps and therefore prevented the activation and development of the coachee's critical reflection abilities. Second, they adopted a profoundly different understanding of a problem as a gap between a current and desired state instead of implementing a preconceived solution (Mohaghegh and Furlan, 2020; Revans, 2011). Third, they began to question their underlying assumptions when framing an I4.0 technology project and acknowledged that implementation of the technology was not a goal in itself, but a means to conduct and experiment or solve a problem (Liker, 2020). Fourth, they began to ensure that the coachee examined their last responses and, through new insights, encouraged them to re-evaluate previously stated goals or actions if necessary to activate and develop critical reflection (Rother, 2010). This became evident as the coaches began to ask more open questions, and the coachee provided even longer answers. Fifth, once the executive sponsors embraced a problem as a learning opportunity, they realized that it was more important to ask questions than provide an answer, especially when assuming the role of the coach.

> As a coach, you should understand the learning process, not the content of the problem. An essential part of the coach's role is to ensure that the questions asked are humble and avoid causing the coachee to disavow and resist the learning opportunity. The group coaching has moved us from defending our solutions to listening and reflecting.

To improve the learning experience for the senior leaders participating in the second AL cycle, the executive sponsors recommended focusing less on the theoretical aspects, providing more practical examples, and spending considerably more time on group coaching.

5.2.2 Action learning cycle 2: developing senior leaders. The responses from the senior leaders participating in the second AL cycle reflected an increased awareness of the mental process behind framing problems and following the scientific method. The senior leaders emphasized that both themselves and their peers were beginning to ask questions in different ways to avoid rushing the problem-framing process, based on facts instead of assumptions or preconceived solutions.

> It [group coaching] has helped me realize that we need to understand the problem before moving into solution mode. Our approach to solving problems used to be very superficial and temporary since it was difficult for us not to pick a technical solution, we knew beforehand. Now I try to understand a problem by talking to people directly involved.

The senior leaders also reflected that the AL program had made them aware of how important fostering a psychologically safe learning environment is for embracing critical reflection and exploring failures. For senior leaders, a safe learning environment is fundamental for employees to understand that they are not obliged to have an answer ready when their leaders ask questions. Therefore, the purpose is to start reflecting and recognizing that structured problem solving (Mohaghegh and Furlan, 2020) is a learning process. Also, being coached requires coachees to be vulnerable, which is difficult without a safe learning environment.

> The first step is to feel safe and vulnerable enough to speak one's mind and share reflections from not succeeding. We now have a higher degree of trust and [psychological] safety because we are on a learning process together.

The senior leaders also observed, both in the daily work and at the I4.0 simulation game, that involving employees in the problems or project leads to faster resolutions. They ask the right questions, since it creates empowerment and ownership when workers are encouraged to reflect during problem framing.

The senior leaders also recommended reducing the amount of theory and scaling up group coaching even more on the third AL cycle. They also highlighted the importance of identifying an existing and relevant project for participants to work on.

5.2.3 Action learning cycle 3: developing department managers, project leaders and specialists. Among the participants in the third AL cycle, a shared realization was that framing a problem and eventually solving it requires taking small, iterative steps. During the I4.0 simulation game, they became aware that small steps and experimentation were essential to succeed with I4.0 adoption. One of the participants highlighted that conducting experiments was a crucial activity in the problem-framing process.

During the first two AL cycles, the department managers, project managers, and specialists observed that the senior leaders and executive sponsors had changed their behavior from giving answers to asking questions. This behavioral change led initially to frustrations among many of them since they felt obliged to have an answer ready every time their leader asked a question. Moreover, they felt that the senior leaders and executive sponsors were eschewing their responsibilities for the problems of the organization. However, the AL cycle provided them with the understanding that they were not obliged to have an answer and solution ready for every problem. As a result, they became aware that it was a learning process to understand a problem in-depth before addressing a solution. According to the participants, the group coaching intervention was essential in uncovering and addressing a flawed mental model that having problems is a negative thing and something to avoid.

The participants also reflected that coping with a high degree of uncertainty required cooperative learning. Several respondents experienced that it had become more acceptable to seek input from other departments and give others feedback since the group coaching process helped them understand the different perspectives. The mix of participants from different departments also contributed to the improved collaborations since the AL cycles helped build relations with colleagues in different departments. Several of the respondents adopted and integrated the group coaching process into their own change initiatives. They experienced those changes more rapidly since the project participants were involved in framing both the problem and the solution:

> Group coaching is useful to move a process and people in a new and better direction. You will get a better result by involving different perspectives from those who are part of the change, instead of just doing things my way.

Several of the participants stated that the purpose of the AL program was unclear initially, indicating that the approach was significantly different from other courses that typically have a sole focus on programmable knowledge.

> I was really out of my comfort zone, and it was really not something that I found comfortable. I think I was more focused on the theory and trying to do it satisfactorily than the ability to try to learn. I would have maybe liked to approach this program with the "what's in it for me" approach—meaning to maybe better understand beforehand where this course could really be beneficial to project managers.

5.2.4 Institutionalization of learning-to-learn capability. At the end of the two-year-long AR project, the senior executives reflected on how the institutionalization of learning-to-learn capabilities was progressing within their organizations. For example, at the lead factory, the general manager as the executive sponsor has the following experience:

> We are in the middle of transcending from consciously incompetent to conscious competent in defining problems, solving problems, utilizing new technologies, facilitating learning through coaching, and asking questions instead of providing the answers as leaders. Of course, we still have a lot to learn, but we are well on our way.

Despite experiencing a high rate of new hires due to explosive sales growth and a corporate re-organization within the VELUX Group, the general manager attributed the positive development to institutionalizing learning into their organizational system. Their project execution, project portfolio management, and strategic processes incorporated the approaches learned in the AL program: defining problems, solving problems, and critical reflection. Moreover, the group coaching sessions and other co-learning processes are now an integrated part of leadership meetings on all levels.

Within the production engineering departments, the executive sponsors have experienced that the AL program has significantly changed how several specialists and project managers reflect and think about solving problems and engaging others, e.g. by coaching and asking questions. However, they must admit that they have not institutionalized the approaches learned at the AL program into their existing processes and governance.

> Our biggest barrier is that we are a fully integrated part of a larger system within VELUX, which has not participated in our action learning program and therefore not adapted to this way of thinking and working.

6. Discussion of actionable knowledge from the action learning initiative

The study's emergent actionable knowledge demonstrates that developing a learning-to-learn capability is a cognitive transformation that develops through AL. Furthermore, we demonstrate that adopting I4.0 is more than acquiring (*P*) programmable knowledge about technologies and implementing best practices. It requires senior leaders to help their organizations frame I4.0 technology projects beyond cost reduction and to engage and collaborate broadly. Therefore, a technocentric approach when implementing I4.0 technology is regarded as ineffective (Rosin *et al.*, 2020; Saabye *et al.*, 2020; Tortorella *et al.*, 2019). Instead, manufacturers must develop a learning-to-learn capability (Powell and Coughlan, 2020) and, through asking insightful questions (*Q*), reframe their perception of how to adopt I4.0 technology. To develop a learning-to-learn capability for enabling I4.0 adoption, we extrapolate the following proposition in the form of five conditions.

6.1 Conditions for I4.0 adoption

The first condition the study reflects for developing a learning-to-learn capability is the presence of SPS abilities (Mohaghegh and Furlan, 2020). As observed, the implementation and adoption of I4.0 requires defining and closing a gap between a current and desired state, which is a problem to be solved and constitutes the core element of Revans' (1971) intertwined Alpha, Beta and Gamma systems. Transcending IPS (Argyris, 1976; Tucker *et al.*, 2002), which is characterized by leaping to a preconceived solution, SPS requires cognitive and behavioral changes. It requires leaders to advance their knowledge and experience to find, face, and frame problems and actions cooperatively (Ballé *et al.*, 2017) and spend considerably more time on this. According to Baer *et al.* (2013, p. 198), the quality of the problem-solving process is determined by how leaders frame problems. Behavior-wise, SPS abilities also require applying the scientific method and experimenting deliberately (Rother, 2010).

The second condition reflects that leaders must serve as learning facilitators (Maalouf and Gammelgaard, 2016). Self-awareness and activation of system Gamma (Revans, 1971) are necessary for leaders to become learning facilitators, and they must possess the ability to critically reflect upon their own basic assumptions, mental models, and behaviors (Boshyk and Dilworth, 2010; Høyrup, 2004; Liker, 2020) by being humble, vulnerable and able to suppress presumptions when asked insightful questions. Moreover, leaders must themselves be proficient in asking insightful questions for framing problems (system Alpha) and solving problems by following the scientific method (system Beta). Leaders can then develop and involve others to facilitate learning and help employees develop their problem-solving skills and grow a more thorough understanding of I4.0 adoption (Cao *et al.*, 2012; Ellinger and Bostrom, 1999).

The third learning-to-learn capability condition reflected by participants is to institutionalize a supportive learning environment. Following Edmondson (1999), this study's emergent actionable knowledge indicates that the AL intervention created a psychologically safe learning environment. The foundation of the safe learning environment is that the participants feel safe to discuss and explore learning from failures and question the underlying shared mental models during I4.0 adoption. In this environment, away from the daily production domain, leaders could practice and develop the ability to ask insightful questions that stimulate upstream and downstream learning (Reason and Torbert, 2001). It is socially acceptable to question, provide, and receive feedback within these new co-learning processes without regressing into defensive behaviors.

Primarily, the group coaching session represents the organizational environment as a microcosm, ideal for addressing and questioning shared mental models that hinder the problem-framing process (Vince, 2002). Here, the participants can share their thoughts and difficulties about scrutinizing their preconceived solutions and beliefs with insightful questioning (Kets de Vries, 2005). Accepting that they may not know the answers, leaders can consciously initiate rapid and frequent learning cycles by conceiving expectations before initiating action and evaluating them against these expectations afterwards (Rother, 2010; Shook, 2008). Participants can gain instant feedback and insights from peers on how others perceive their questioning techniques as an effective way to improve their SPS abilities (Cho and Linderman, 2019; Rother, 2010).

The fourth learning-to-learn capability condition is the underlying organizational learning scaffold (Kokkonen, 2014; Sproull, 2010) that invokes and connects the other four conditions. The institutionalized learning scaffold encompasses Revans' (1971) intertwined system of Alpha, Beta and Gamma. The core element of the learning scaffold is the leaders, as learning facilitators, who develop and train subordinates to apply SPS and become learning facilitators themselves. The learning scaffold consists of facilitators who deliberately institute learning and problem-solving routines for their subordinates, such as coaching (Rother, 2010) and A3 thinking (Shook, 2008).

The final and fifth condition is the presence of programmable knowledge (*P*) about I4.0 adoption. *P* tends to be overlooked across the AL literature, with the focus mainly on *Q*. *P* is regarded as the basis of system Alpha, which is based on a prior understanding of the problem's history, context and previous attempts to solve it (Coughlan and Coghlan, 2021). The *Q* factor assists us in figuring out whether or not *P* – or at least a portion of it – is legitimate (Boshyk and Dilworth, 2010). The participants mainly obtained programmable knowledge about I4.0 technologies and adoption during the I4.0 simulation game (Mortensen *et al.*, 2019), which first concerns an understanding of the purpose and potential behind the different I4.0 technologies. Second, the I4.0 simulation game provided the participants with programmable knowledge about people-centric conditions for successfully adopting I4.0, such as the consequences of disregarding a focus on competency development, the definition of value creation, and governance of I4.0 adoption (Mortensen *et al.*, 2019).

6.2 Outcome

Since the AL program was conducted during a period of significant growth, it is difficult to isolate the operational effects of the program. However, the VELUX factory improved their number of projects finished on time from 9% to 100% initiated after the second AL cycle, and the structured framing of projects increased from 40% to 100%. Moreover, our findings reflect that the organization's project deliveries are improving, as illustrated in Table 5.

6.3 Implications for practitioners

Besides the theoretical contributions discussed above, the actionable knowledge that emerged from this study also provides a set of specific implications for manufacturers in how to develop a learning-to-learn capability enabling I4.0 adoption. We therefore recommend, although it is not intended as a rigorous protocol, following a phased learning-to-learn capability building approach in conjunction with the deployment of I4.0 technology.

First, executive sponsors must embrace and promote I4.0 adoption as an emergent AL process by acceding to Revans' (2011, p. 76) principle of insufficient mandate: "*Those unable to change themselves cannot change what goes on around them*." Without the ability to abandon ideas that have been proven incorrect (insufficient mandate over oneself), it is impossible to introduce actions that are known to be correct, which is a necessary effect of AL (Revans, 2011). Executive sponsors must start developing their abilities as learning facilitators by becoming (1) aware of their own basic assumptions, mental models, and behaviors, (2) able to receive and ask insightful questions by developing their own coaching routines, and (3) able to frame and solve problems using the scientific method.

Second, the executive sponsors must, together with an accoucheur (an AL facilitator), design an AL program to be integrated with existing plans for digital transformation. The purpose of this AL program is twofold:

(1) Finding, facing, framing, and solving concrete I4.0 adoption-related problems by considering these as problems (and not puzzles) of closing a gap between a current and desired state.

(2) Developing the ability of subordinate leaders to solve problems independently, and as learning facilitators, to offer coaching to help others learn to solve problems using the scientific approach.

As recommended by Pedler and Abbot (2013), an AL program should initially contain activities similar to those described in Table 3. The existing lean literature offers many methods, such as A3 Thinking (Shook, 2008) and Toyota Kata (Rother, 2010), to supplement the AL program and develop the participants' abilities to apply the scientific method and

Project goal (Simplified)	New approach	Effect on project outcome
Reduce quality errors in panes production using IoT systems	• The project is spending more time on defining the problem by talking to stakeholders and gathering facts • The project manager is coaching project participants and receives coaching from the project sponsor • They are experimenting and testing our hypothesis and possible solutions	Without learning from the group coaching process, the project would only uncover a third of the root causes
Improve a new travel settlement process	• The project is reframing the problem from reducing finance's time spent supporting the settlement process to reducing the time the superuser spends on travel settlement • The project manager involves the superusers in solving the problem	Implementation of a sustainable solution since the superuser was part of defining and implementing the solution
Improve panes production using IoT systems	• The project is deliberately spending more time gathering facts and defining the problem • The project is experimenting with several solutions before implementation • The project involves workers in the planning phase and in conducting experimentation	The project identified a more effective solution than the one initially conceived
Implementing new wood component production line and associated new technology	• The project prioritizes time to frame the goal and current state in detail, despite being on a tight schedule, and uses explorative questioning • The project group meets every day to learn from the last (small) step and define the next small step	The project succeeded with a big new project on time, despite it being imposed on short notice by top management with tight schedules
Moving the existing production line to prepare for a new one	• The project involves the workers defining the problem, identifying, and experimenting with solutions by asking explorative questions • The project uncovers different framings of the problem and solution before deciding by experimenting instead of discussing	The project identified a more effective solution than the one initially conceived
Aluminum flashing component production and packing line	• The workers framed and resolved several small problems within their own control and influence through daily coaching sessions. In addition, they learned how to understand and use the many production performance data available	The project reported an 11% productivity increase The intervention also resulted in an improved work climate, according to workers' representatives
Aluminum cladding component production line using IoT systems		Overall equipment effectiveness (OEE) improved from 45 to 60 The intervention resulted in an improved work climate, according to workers' representatives

Table 5.
Examples of improved project deliveries

coaching routines. It is important not to discard programmable knowledge about I4.0 technologies and their adoption, but we suggest that this knowledge is not merely attained in a traditional classroom or conference reference setting, but by, for example, attending a simulation game at a smart I4.0 production laboratory.

Third, as the AL is deployed through an organization and leaders become proficient as learning facilitators, the newly adopted practices and methods underlying SPS and critical reflection should be diffused and anchored within the existing system. These practices and methods could be incorporated into the existing strategy deployment, portfolio and project management processes.

7. Conclusion

In this two-year AR study, we examined how the roof windows manufacture VELUX developed their learning-to-learn capabilities for enabling I4.0 adoption. Derived from the emergent actionable knowledge from conducting the three action cycles, we found that adopting I4.0 requires more than acquiring programmable knowledge about I4.0 technologies and implementing best practices (Machado *et al.*, 2021; Saabye *et al.*, 2020). It is also about asking insightful questions by fostering a learning-to-learn capability through AL (Powel and Couglan, 2020). Moreover, this study demonstrates that the institutionalization of an organizational learning scaffold (Kokkonen, 2014; Sproull, 2010), encompassing leaders as learning facilitators (Maalouf and Gammelgaard, 2016), is an essential leadership role during Industry 4.0 adoption. We summarize the significant findings of this AL research study as three core outcomes.

(1) Developing a learning-to-learn capability is a core construct and enabler for manufacturers to adopt I4.0 successfully.

(2) Institutionalizing an organizational learning scaffold encompassing the intertwined learning processes of systems Alpha, Beta, and Gamma serves as a significant way to develop a learning-to-learn capability.

(3) Group coaching is an effective AL practice for invoking system Gamma, developing leaders to become learning facilitators, and developing systematic problem solvers able to understand and utilize the I4.0 technologies.

We observed that manufacturers' technocentric approach to I4.0 adoption is insufficient for undergoing a digital transformation. Instead, it is more effective to think of I4.0 as an emergent AL process. By adopting a learning-to-learn perspective, manufacturers are encouraged to develop a supportive learning environment by institutionalizing an organizational learning scaffold as an enabler for I4.0 adoption. We have shown (through participation, observation, and reflection) the significance of concurrently engaging system Alpha, system Beta and system Gamma (Revans, 1971) to enable I4.0 adoption. Because the focus is on solving a specific problem, Alpha is necessary but insufficient to develop a learning-to-learn capability. System Alpha must be intertwined with system Beta to develop a learning-to-learn capability that teaches employees to solve problems using the scientific method (Smith, 1997). To become a learning facilitator, leaders must monitor and critically reflect (Cunliffe, 2004; Høyrup, 2004) on the actions and learning generated from system Alpha and system Beta activities, which is what system Gamma is for (Smith, 1997). Our AR results indicate that the group coaching practices positively influenced the leader's critical reflective practices and their organization's SPS abilities. Following Edmondson (1999), the group coaching practices enabled a safe learning environment where the participants felt comfortable discussing and exploring lessons from failures and questioning their underlying mental models.

7.1 Limitations

The findings of this AL research study are limited in their generalizability because they were conducted inside a particular organizational environment, which can be considered immature in its adoption of I.40. On the other hand, while the practical information derived from this study may be specific to the case company's environment, it contributes to a generalizable lesson that may motivate both practitioners and scholars. This research can encourage engagement in the development of conditions for a learning-to-learn capability and the positive effects of intentionally designing AL interventions with Revan's (1971) system Alpha, system Beta and system Gamma learning processes. Another limitation is the timeframe devoted to the study. A two-year longitudinal study is a legitimate duration to measure the outcomes of the initial AL intervention. However, most manufacturers require many years to completely embed a new method of working across their whole organization.

7.2 Future research

To advance this research and examine the validity of our findings, we suggest testing the application of our AL interventions to uncover conditions for I.40 adoption in other operation management settings. Qualitative approaches would be helpful to uncover other mechanisms that explain how people-centric approaches support higher levels of Industry 4.0 adoption. We also suggest analyzing the conditions discussed in this paper quantitatively.

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