Future Operator Competence and Learning Design in Automotive Final Assembly: A Human-Technology Perspective

A case study at Volvo Cars

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Abstract

The automotive industry is undergoing rapid technological change driven by increasing automation and digitalization. This thesis investigates how these developments will impact competence requirements in automotive final assembly within a 5–10 year period and how suitable learning approaches can be designed for the time- and resource constrained conditions of a high-volume assembly plant. The study was conducted as an exploratory qualitative case study at Volvo Cars' final assembly plant in Torslanda, Sweden. The research method included a literature review, semi-structured interviews with key roles, shop-floor observations, and internal document analysis.

The findings indicate that final assembly is unlikely to be fully automated within 5–10 years due to product variety and the need for human adaptability. Manual and procedural assembly skills will remain essential, but will increasingly be complemented by digital literacy, system understanding, cross-domain problem-solving and AI literacy as automation, data-driven monitoring and AI/vision-based quality systems expand. Social and collaborative skills will also remain important for stable operations in the resulting human-technology collaborative environment.

The current learning environment is constrained by high information load, inconsistent structure, limited verification of learning outcomes, and highly dependent on mentors and production conditions. To address these challenges, the thesis proposes a context adapted learning management system using microlearning, embedded assessments, distributed practice and mechanisms for engagement, complemented by QR-based contextual learning. XR-based scenario training is discussed as a future development possibility. A prototype was developed as a proof of concept and evaluated through stakeholder feedback.

Keywords: operator competence, upskilling, learning management system, XR, final assembly.

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List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

AGV	Automated Guided Vehicle
AI	Artificial Intelligence
AMR	Autonomous Mobile Robot
AR	Augmented Reality
CLT	Cognitive Load Theory
CTML	Cognitive Theory of Multimedia Learning
DT	Digital Twin
EQ	Emotional Intelligence
ICT	Information and Communication Technologies
IoT	Internet of Things
IPM	Incremental Prototyping Method
KPI	Key Performance Indicator
LMS	Learning Management System
ME	Manufacturing Engineering
OECD	Organisation for Economic Co-operation and Development
OIS	Operator Instruction Sheet
PA	Plant Academy
PL	Plant Launch
PLC	Programmable Logic Controller
POPS	Proactive Operator and Process Study
QR	Quick Response
SBT	Scenario-Based Training
SWE	Simulated Work Environment
VCMS	Volvo Cars Manufacturing System
VE	Virtual Environment
VR	Virtual Reality
WES	Work Element Sheet
XR	Extended Reality

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1
Introduction

This chapter presents the background, case company, aim and scope of the thesis.

1.1 Background

The automotive industry is undergoing significant change driven by rapid technological development, changing market demands and increasing pressure for sustainability and operational efficiency, according to the annual report for Volvo Cars (2026).Traditional production systems, historically designed for long product life cycles and stable processes, are increasingly challenged by the need for flexibility, frequent model updates, and digital integration. As a result, automotive manufacturers must continuously adapt both their technologies and organizational structures to remain competitive.

In recent years, manufacturing industries have been further shaped by the ideas associated with Industry 4.0 and, more recently, Industry 5.0. Industry 4.0 is commonly used to describe a shift toward more connected and data-driven production through automation and digital integration (Kagermann et al., 2013), while Industry 5.0 extends this perspective by placing a stronger focus on human-centric production, resilience and sustainability (Breque et al., 2021). Together these perspectives highlight that industrial change is not only technological but also socio-technical, affecting how work is organized and how people interact with production systems.

For automotive manufacturers such as Volvo Cars, future competitiveness depends not only on the successful adoption of automation, digital tools, and connected manufacturing systems, but also on how these technologies are integrated with human work. Production systems must be designed to support collaboration between operators and technology, enabling both efficiency and adaptability while maintaining high standards of quality and ergonomics.

Final assembly plays an important role in this transformation. Unlike highly automated production areas such as the body and paint shop, final assembly remains labor-intensive and must handle high product variety, short takt times and frequent changes in models, variants and options. At the same time, technology such as automation, digital support systems and connected manufacturing, are being explored for the final assembly environment. These developments create opportunities but also introduce uncertainty regarding how work will be performed and how roles may evolve.

As production systems evolve, questions emerge regarding future competence needs and how the company can ensure that skills and knowledge develop with technological and organizational change. In parallel, it becomes important to understand how learning and competence development can be organized in ways that work under the conditions of final assembly, where time pressure and operational demands can limit opportunities for training and reflection.

1.2 Introduction to Volvo Cars

Volvo Cars is a Swedish premium automotive manufacturer founded in 1927 and headquartered in Gothenburg, Sweden. The company's purpose is "to give people the freedom to move in a personal, sustainable and safe way" and is globally recognized for its leading position in automotive safety, according to the annual report by Volvo Cars (2026). Several innovations contribute to that heritage, from the three-point seatbelt invented in 1959, to the multi-adaptive seatbelt introduced in the new EX60 year 2026. In 2025 Volvo Cars sold 710.000 vehicles across 100+ markets, operating manufacturing sites in Torslanda (Sweden), Ghent (Belgium), Charleston (US), Chengdu, Daqing, Taizhou (China) and a new site under construction in Košice (Slovakia). The company is publicly listed on Nasdaq Stockholm and is part of the Geely Group.

Volvo Cars strategy focuses on electrification, cost-efficient growth and regional resilience. According to the annual report by Volvo Cars (2026), accelerating technology development within the automotive industry together with increasing de globalization and hyper competition as the main challenges, increasing the pressure of being more cost-efficient and flexible.

In the sections below, brief descriptions of departments within Volvo Cars with relevance for the study will be presented.

1.2.1 Final Assembly Shop

The manufacturing plants are most often divided into three parts: body shop (where the body is welded together), paint shop (where corrosion protection and paint are applied) and final assembly (where painted bodies are married with the powertrain, electrical systems, interior and outer chassis parts) to produce a complete car. Some sites only operate final assemblies and source painted bodies from other sites, however Volvo Cars Torslanda is a complete site with body, paint and final assembly operations.

The final assembly shop in Torslanda has a capacity of 290.000 cars annually with a takt time of 60 seconds, corresponding to 60 cars per hour. The shop currently assembles three car models: XC60, XC90 and EX60.

1.2.2 Plant Academy

Plant Academy is responsible for the onboarding and upskilling of new and existing employees within the factory. The department offers introduction and basic skill training (for operators), introduction to the plant for the engineering department, courses in leadership, lean methodology, electrical safety and a range of other factory-relevant topics.

Each manufacturing site operates its own Plant Academy organization, scaled to local needs, with full-time instructors who teach and continuously develop the educational packages to keep them actual with process changes, standards and technologies. The aim is to ensure a common baseline of competence, safety and standards across all sites.

1.2.3 Plant Launch

Plant Launch is responsible for ensuring that the plants have the right conditions for building new car models and during larger model year changes with regards to people and processes. Work typically begins years in advance, progressing from virtual builds to pilot builds in offline environments and then controlled builds on the line to validate processes, tooling and ergonomics. The team coordinates with the engineering department and manufacturing engineering developing industrial tooling and authors the work standards (OIS/WES) that lays the foundation for operator training for the coming model cycle. Plant launch is also responsible for operator readiness before major car launches, coaching operators in both offline and online training.

1.2.4 Manufacturing Engineering

Manufacturing engineering (ME) is responsible for the process technologies used in manufacturing. The department designs, procures and plans and executes the installation of equipment and production lines. ME is also responsible for driving innovation through research into new technologies such as robotics, automation, AI, and digital factory technology.

Each manufacturing site operates its own ME organization that maintains processes, standards and methods as products and technologies evolve with the aim of securing a common baseline of manufacturability, safety and quality across all sites.

1.3 Aim and Research Questions

The aim of this thesis is to investigate future skill and knowledge requirements for operators at Volvo Cars in the context of increasing automation and digitalization and to analyze how these can be developed into the competence needed for future final assembly and linked to operational efficiency. The following research questions can be derived from the aim and background:

- RQ1: How will technological changes influence operator roles within 5–10 years and what are the resulting future skill and knowledge requirements for operators at Volvo Cars?
- RQ2: What approaches for training and competence development are suitable within 5–10 years?
- RQ3: What potential efficiency gains can be associated with improved skills, knowledge, and learning methods in final assembly operations?

1.4 Limitations

As stated above, this report is a case study and will focus on final assembly at Volvo Cars, considering both the current state and an envisioned future state. Upstream production processes are outside the scope of this study. The data collection will be limited to Volvo Cars' plant in Torslanda, Sweden due to accessibility, and findings will therefore not be generalized. It may however be possible to draw some generalized conclusions across other Volvo Cars plants due to similar prerequisites and operations, but this is not done or addressed in the report. Further, while the results may also be relevant for other fast-paced and labor-intensive manufacturing contexts, such generalizations will not be addressed.

The report will not focus on the workstation layout or the overall production system, but rather on which technologies will influence final assembly operations and what skills and knowledge are needed for this in the future. A prototype was developed to make the proposed learning concepts tangible, but it functions merely as a proof of concept rather than a production-ready system. The prototype was used for demonstration purposes and to gather stakeholder feedback and was not deployed in live production. Furthermore, all envisioned functionalities are not fully developed in the prototype, mainly aspects regarding advanced XR-technologies, which limits the feedback's concreteness regarding these parts. Since the prototype was not tested in live production, the thesis does not provide measurable effects on operational KPIs from its use, and the efficiency implications are instead discussed qualitatively based on empirical insights.

2

Theoretical Framework

In this chapter, the necessary background knowledge related to the thesis is presented and later used as a lens for interpreting the findings.

2.1 What is a Skill Gap?

According to Rodrigues et al. (2021), a skill can be defined as the ability to perform a task effectively. Skills are commonly divided into three categories. Physical skills refer to how well an individual can carry out physical tasks. Cognitive skills involve the ability to perform intellectual activities such as problem-solving. Lastly, social skills refer to abilities related to interacting with others, including teaching, managing, and influencing. Another widely used classification distinguishes between soft skills and hard skills. Soft skills enable employees to function and integrate effectively within the workplace and include attributes such as leadership and motivation. In contrast, hard skills are task-specific abilities that allow employees to perform and compete in technical, scientific, or physical tasks (Lyu & Liu, 2021).

Skill gaps can be defined as a mismatch between the skills required by employers and those possessed by employees (Rikala et al., 2024). Skill gaps are a global concern for organizations. According to an industry-level analysis by the WEF (2025), employers estimate that 39% of workers skills will change by 2030. The average half-life of skills is 5 years and, in some fields, even just 2.5 years (Cappelli et al., 2025). Organizations experiencing skill gaps face several negative consequences, including increased workloads for existing staff, difficulties in implementing new technologies and ways of working, and challenges in meeting customer demands, as highlighted in policy reports by the OECD (2024). Addressing these skill gaps is therefore critical, as closing them is expected to increase productivity by an average of 17% across OECD countries (Andrews et al., 2025).

2.2 Industrial Revolutions and the Evolution of Skills in Manufacturing

The development of modern manufacturing systems has been shaped by successive industrial revolutions, each characterized by major technological and organizational transformations that have changed production processes and work practices. The first industrial revolution, beginning in the eighteenth century, introduced mechanized production powered by steam engines. This period marked a shift from manual craftmanship to machine assisted manufacturing, leading to increased productivity and improvements in overall welfare and standards of living (Groumpos, 2021).

The second industrial revolution was characterized by the introduction of electricity, assembly lines, and mass production principles such as standardization. These developments enabled high production volumes and laid the foundations of modern industrial production systems (Groumpos, 2021). Work became increasingly specialized, with narrowly defined tasks designed to maximize efficiency.

The third industrial revolution, also referred to as the automation revolution, represented a major shift through the introduction of computers, programmable logic controllers (PLCs), and industrial robots. For the first time, human labor could be partially replaced by automated systems. This period was characterized by the integration of digital technologies and information and communication technologies (ICT) across the manufacturing and service sectors. According to Didier (2024), these advancements led to significant reconfigurations of labor markets and skill requirements. Most notably, it formed the emergence of a specialized knowledge workforce termed as "knowledge workers" whose roles centered around ICT, system maintenance and development.

However, technological progress during this period did not benefit all workers equally. Didier (2024) argues that this period marked the start of a growing division of the labor market into a primary segment of highly skilled, technologically educated professionals and a secondary segment of lower-skilled blue-collar workers. This polarization of skills is also discussed by Vallas (1990), who reviewed research on technological change and work organization. While upgrading theorists suggested that automation would free workers from machine-paced labor and increase autonomy and cooperation, deskilling theorists argued that automation represented a continuation of managerial control and further reduced workers technical understanding. Rather than supporting a single perspective, Vallas (1990) concluded that upgrading and deskilling processes often coexisted within the same organizations and industries, resulting in a polarized skill structure.

Building on these developments, the fourth industrial revolution, also referred to as Industry 4.0, represents a shift towards highly interconnected and digitalized manufacturing systems. Industry 4.0 is characterized by the integration of cyber-physical systems, the internet of things (IoT), big data analytics, and cloud computing across production environments (Kagermann et al., 2013). These technologies enable real-time data exchange between machines, systems, and organizational levels, allowing for increased transparency, flexibility, and efficiency.

Unlike the earlier automation wave that replaced manual labor, Industry 4.0 increasingly transforms the nature of work itself. Operators are expected to interact with digital interfaces, monitor processes, interpret data, and respond to system disturbances. This development leads to hybrid work roles where traditional operational tasks are combined with digital, analytical, and problem-solving activities (Gorecky et al., 2014; Romero et al., 2016). As a result, competence requirements expand beyond manual proficiency to include digital literacy, system understanding, and continuous learning capabilities (Hecklau et al., 2016).

This transformation challenges the historical separation between blue-collar and knowledge-based work that emerged during the previous industrial revolutions. Technological knowledge will be expected to be embedded in shop-floor activities, which reduces the distinction between operational and technical roles. However, several authors argue that the positive potential of Industry 4.0 is highly dependent on organizational learning strategies and workforce development practices (Hecklau et al., 2016; Romero et al., 2016). Without clear competence development tools and strategies, realizing the full potential of Industry 4.0 will be challenging.

More recently, the concept of Industry 5.0 has emerged as an evolution of the digitalization agenda, shifting focus from purely technology driven optimization toward a more human-centric, sustainable and resilient production model. While Industry 4.0 has focused on connectivity, automation and data, Industry 5.0 tries to highlight the complementary strengths of humans and intelligent technology (Breque et al., 2021). Rather than focusing on how technology can substitute humans, Industry 5.0 promotes the need for collaborative human-machine systems that places the wellbeing of the worker at the center of the production process.

In this context, capabilities such as creativity, adaptability, and contextual understanding which are unique to humans, are increasingly viewed as equally important as technical or digital competencies. Operators are expected to work closely with advanced automation and decision-support systems where technology acts as an enabler of learning, problem-solving and flexibility, rather than as a replacement for human input (Nahavandi, 2019). This further blurs the traditional occupational roles and reinforces the need for more thorough competence profiles.

The development of the industrial revolutions shows a transformation of work from manual craft-based production toward increasingly complex socio-technical systems. While earlier technological waves lead to the separation of manual and technical roles and polarization of skills, today's manufacturing systems are moving toward more integrated competence requirements. Industry 4.0 and Industry 5.0 demand that operators are not only executors of predefined tasks but instead are active participants in human-technology collaborative environments. This evolution will place a growing importance on learning processes, adaptability, and the continuous development of skills as production environments become more dynamic and interconnected. In labor-intensive contexts such as final assembly, where high product variety and frequent changes are usual, the ability to combine operational expertise (process understanding) with digital interaction and problem-solving capabilities become particularly important. Therefore, understanding how skills, knowledge, and competence are developed, transferred, and sustained in these evolving production systems is central to both achieving full technological and human potential.

2.3 Upskilling, Reskilling and Pre-skilling

As discussed in the previous sections, skill gaps emerge when specific skills or knowledge areas no longer align with required competence. In the literature, two related but conceptually distinct responses to such gaps are commonly discussed: upskilling and reskilling (Breque et al., 2021; Cappelli et al., 2025).

Upskilling refers to broadening existing skills or knowledge to meet new or increased demands within an existing role (G. Braun et al., 2024). Upskilling hence assumes a degree of continuity in work roles, where core tasks remain similar but are complemented by additional competencies. In manufacturing, upskilling is relevant during increasing task complexity, broader responsibility, and the integration of digital tools that require a higher level of cognitive or analytical capability. Reskilling in contrast refers to the acquisition of completely different skills to be able to transition into a new role or significantly redefined work duties (G. Braun et al., 2024). While upskilling builds on existing competence profiles, reskilling implies a more fundamental reconfiguration of skills. Reskilling might be relevant when technological change not only affects how work is done but also what kind of work is required.

A third approach that is currently gaining traction is pre-skilling. Whereas upskilling and reskilling are reactive, addressing already emerging or clearly identifiable skill gaps, pre-skilling refers to proactively preparing workers for roles, tasks and skill demands that cannot yet be fully specified but are expected to arise as technologies evolve. This concept is discussed in both academic literature (Cappelli et al., 2025) and industry reports (ManpowerGroup, 2024). Pre-skilling focuses on developing soft skills such as learning agility, curiosity, resilience and adaptability over hard skills such as programming, which enable individuals to acquire new competencies more rapidly as needs emerge (Cappelli et al., 2025).

In complex and rapidly evolving production environments, such as automotive final assembly, these different skill development approaches are likely to coexist rather than being different strategies. While reskilling may be necessary when new technologies fundamentally alter job structures, upskilling becomes important for enabling operators to handle increasing task complexity, digital interfaces, and broader process responsibility. Pre-skilling complements these approaches by preparing the workforce for ongoing technological change and uncertainty.

2.4 Learning Theories

This section introduces learning theories used to analyze current learning practices and to guide the design of a proposed future learning approach.

2.4.1 Effective Learning Techniques

There are several different learning techniques used in various contexts. Among these, Dunlosky et al. (2013) ranks some of the most used ones based on their generalizability over various conditions such as learning conditions, student characteristics, and material of the content being learned. From this study, the authors conclude that the learning techniques with the highest utility – i.e., are most appropriate to use in various contexts – are practice testing, as well as distributed practice. Practice testing includes activities such as self-testing through low stake quizzes or flashcards which enables the learner to easily and adequately identify gaps in the acquired knowledge as well as retain already acquired knowledge. Distributed practice regards study sessions spaced over time instead of cramming given the same amount of time for studying. Following, on a moderate utility rate, comes the learning techniques elaborative interrogation (repeatedly ask yourself the question "why?"), self-explanation (trying to relate new information to already known, or steps in a problem solving process), and interleaved practice (mixing multiple topics or subjects in one session). The learning techniques with the lowest utility rate according to the authors are; summarization, highlighting, keyword mnemonic (associate new words with similar sounding words), imagery use for text learning (visualize through mental images), and rereading.

2.4.2 Psychological Safety

Teams where the members have a shared belief that the team is safe for interpersonal risk-taking are defined by Edmondson (1999) as psychological safety. This means that people feel comfortable asking questions, admitting mistakes, and proposing new ideas without fear of negative consequences, embarrassment, or punishment to their self-image, status, or career. Fostering the feeling of psychological safety within a team leads to greater communication, knowledge sharing and error reporting – not because more errors appear, but rather because people feel safe to surface occurred errors (Edmondson, 1999; Newman et al., 2017). This, in extension, leads to greater engagement in various learning behaviors such as seeking feedback, sharing ideas, reflecting on results, or discussing mistakes (Edmondson, 1999). Further, Edmondson concludes that the higher degree of learning behavior leads to better performance. However, Edmondson further discusses that this may not always be the case since learning behaviors consume time and do not assure results, and thus, instead leading to reduced efficiency and performance, e.g. in cases of highly routine tasks with little to no need for improvement.

2.4.3 Cognitive Load Theory

When designing learning tools, understanding how the human brain processes information is important. Cognitive Load Theory (CLT) provides valuable insight into how the limitations of human working memory influence learning and problem-solving. The core idea of CLT is that working memory only has a very limited capacity and can typically only handle a few tasks or elements of information at once. When working memory is exceeded, learning becomes inefficient or breaks down (Sweller, 2010).

CLT differentiates between three types of cognitive load that determine how well learners can process and remember new information (Sweller, 2010):

- Intrinsic cognitive load refers to the complexity of the material itself. It depends on the number of interacting elements and the learner's prior knowledge. While this type of cognitive load cannot be eliminated, it can be managed. One way to do this is by decomposing complex tasks into smaller, more manageable steps, so the learner only needs to process a limited number of elements at a time. Another strategy is by increasing difficulty gradually, starting with simple low interaction components of a task and then adding more complexity as the learner gains experience.
- Extraneous cognitive load refers to how information is presented rather than the task itself. Poor instructional design, for example by presenting information on cluttered screens, presenting audio and text simultaneously or including distracting visual details, fills up the working memory without contributing to learning. Minimizing extraneous load is therefore crucial when designing learning tools.
- Germane cognitive load is the effort invested in building and integrating newly learned information into existing mental models. It is the type of cognitive load that directly contributes to learning. Germane load is highest when intrinsic load is kept at a manageable level and extraneous load is minimized, since this frees up mental resources which can be devoted to constructing knowledge rather than dealing with unnecessary complexity. Germane load can be supported by facilitating activities that encourage active engagement, reflection and critical thinking.

2.4.4 Cognitive Theory of Multimedia Learning

While CLT explains how limited working-memory constraints learning, Cognitive Theory of Multimedia Learning (CTML) explains how learners process words and pictures and how multimedia instructions should be designed to support learning (Mayer, 2017). CTML is based on three assumptions: dual-channels principle – people have separate channels for visual and verbal information, limited-capacity principle – people can only process a few pieces of information in each channel at any given time and active processing principle – meaningful learning can only occur when people engage in appropriate processing during learning.

Building on these assumptions, CTML presents 11 design principles aiming to reduce extraneous processing, managing essential processing, and foster generative processing (Mayer, 2017). These aims align with CLT's distinction between extraneous, intrinsic and germane load.

To reduce extraneous processing, CTML proposes the following principles (Mayer,

2017):
- Coherence principle – Interesting but unnecessary information should be excluded.
- Signaling principle – Essential information should be highlighted.
- Spatial contiguity principle – Text should be placed near the corresponding part of a graphic.
- Temporal contiguity principle – Corresponding graphics and narration should be presented simultaneously.
- Redundancy principle – Avoid presenting identically spoken and printed text.

To manage essential processing, CTML recommends (Mayer, 2017):
- Segmenting principle – Break complex processes into user-paced segments.
- Pre-training principle – People learn better when they learn key terms prior to a lesson.
- Modality principle – Spoken narration with graphics performs better than on-screen text with graphics.

To foster generative processing, CTML identifies (Mayer, 2017):
- Personalization principle – Use conversational rather than formal wording.
- Voice principle – Use human voices rather than machine voices.
- Embodiment principle – When on-screen agents are used, human-like gestures and movement improve learning.

2.4.5 On-the-job training vs Off-the-job training

A key distinction in training design is between on-the-job and off-the-job training where the differentiating factor is primarily in which environment the training occurs. On-the-job training occurs in the natural work environment whereas off-the-job training can occur either in a simulated environment designed to simulate the natural work environment or a contrived environment created specifically for the training but lacking resemblance of the work environment (Martin et al., 2013).

On-the-job training lets employees get exposure directly to tasks, tools, and workplace conditions. Common types of on-the-job training include job shadowing, job rotation, and internships, where learners can observe or perform work tasks (Martin et al., 2013). This approach is the most desirable due to its authenticity and the possibility of directly putting theory into practice. However, learning can be affected by pressures in production and the fear of failing in front of one's colleagues. Also, while this type of training does not cost extra in terms of salary to hired trainers, there are hidden costs in time spent learning and errors made during training. Furthermore, there exist quality and safety risks when learners learn during real operations.

Off-the-job training takes place outside the work environment and includes formats such as lectures, simulations, games, and role play. These approaches allow for a higher degree of control which enables standardization, structured feedback, and reduced operational risk (Martin et al., 2013). Simulations, especially, provide "safe, structured, engaging and effective practice opportunities" for complex or high-stake tasks that would be too risky or costly to practice in real life. The trade-off is realism which can make transfer of knowledge more challenging if the training environment does not fully replicate the real work environment. However, this does not mean that all aspects of the training environment need to be replicated. It is the similarity of the important cognitive and procedural elements that determine if skills transfer effectively, not visual realism (Wickens et al., 2013). If the training environment captures the key decision-making processes, response patterns, and sequences of actions needed in the real task, effective learning can still occur even if the physical environment looks or feels different. Vice versa, trying to create highly realistic environments that fail to fully match the real environment, can introduce distracting complexity and promote incorrect habits (Wickens et al., 2013).

2.5 Technologies and Learning Concepts

While the previous section explains learning from a theoretical perspective, this section focuses on practical concepts and technologies that can be applied in the proposed solution.

2.5.1 AR

Augmented Reality (AR) refers to interactive systems that overlay virtual information onto the physical environment in real-time. Unlike virtual reality (VR) which creates a fully immersive digital environment, AR enhances the existing physical environment by allowing users to interact with both virtual and real elements simultaneously (Buchner et al., 2021; Cheymol et al., 2025). This real-time alignment between physical and virtual elements enables users to access information directly within their work or learning environment, reducing the need to shift attention between separate instructional media and physical tasks.

AR can be implemented through several formats. Common approaches include see-through AR using head-mounted displays which present digital overlays within the user's field of vision, spatial AR where information is projected directly onto physical objects or surfaces and mobile AR where smartphones or tablets are used to visualize augmented content (Buchner et al., 2021). Each format offers different levels of immersion, mobility, and interaction which may influence learning outcomes and usability in industrial contexts.

Literature suggests that AR has potential as a learning and training support technology. By situating information directly within the physical task environment, AR can facilitate understanding of complex procedures (Chen & Karsen, 2025), support just in time guidance (Buchner et al., 2021) and reduce the need for mental translation between instructions and actions (Cheymol et al., 2025). Under appropriate design conditions, AR-based learning environments can improve task performance and reduce cognitive load compared to traditional instructional media (Buchner et al., 2021). The positive effects have been observed particularly in procedural learning contexts such as assembly and maintenance, where spatial understanding and sequential task execution are important.

In addition to performance-related benefits, AR has been associated with increased learner engagement and motivation (Chen & Karsen, 2025). The interactive and contextualized nature of AR environments can support active learning processes, allowing users to explore, manipulate, and apply knowledge directly into realistic work scenarios (Prasetya et al., 2024). The integration of digital guidance directly into work activities enables learning to occur alongside task execution. Furthermore, AR can be combined with gamification mechanics (progress indicators, challenge structures and rewards) to sustain attention and provide immediate performance feedback within the flow of work, further strengthening participation and knowledge retention (García & Gracía, 2025).

However, research also highlights that the effectiveness of AR is highly dependent on system design and implementation. Poorly organized AR interfaces may introduce excessive information, visual clutter, or distractions which can increase cognitive load and negatively affect learning outcomes (Buchner et al., 2021). Object physicalization also matters, when users must alternate frequently between virtual and real objects, interaction efficiency can suffer (Cheymol et al., 2025).

2.5.2 Digital-twins

Digital twin technology refers to the creation of a virtual, digital representation of a physical object, system, or process, continuously updated with real-world data. An industry report from McKinsey & Company (2024b) defines a digital twin as “a virtual replica of a physical object, person, or process that can be used to simulate its behavior to better understand how it works in real life”, typically connected to real-time data streams that allow the virtual model to mirror the state and behavior of its physical counterpart. The concept originates from product lifecycle management, but it has expanded significantly due to advancements in Internet of Things (IoT), cloud computing, artificial intelligence (AI) and extended reality technologies (XR) (Attaran & Celik, 2023). These technologies enable data acquisition, large-scale storage and computing, real-time analytics, and interactive visualization, acting as the backbone of modern digital twins.

At its core, a digital twin connects a physical system with a virtual model through continuous data exchange, as described in the industry report by McKinsey & Company (2024b). IoT sensors collect operational data from machines, tools, or processes, which are transmitted via cloud infrastructures and processed using AI to generate insights, detect anomalies or predict system behavior (Attaran & Celik, 2023). XR technologies further enable users to interact with the virtual model in immersive or augmented environments using 360 vision and sound, enabling tasks such as monitoring, remote assistance and learning (Attaran & Celik, 2023; Martínez-Gutiérrez et al., 2023). This combination allows digital twins to function both as accurate models but also as interactive environments where alternative scenarios can be tested and learned safely and efficiently with a high degree of realism, thereby increasing user engagement (Hassan et al., 2024; Martínez-Gutiérrez et al., 2023).

Research show that digital twins have potential for operator learning and competence development. Digital twins can provide a realistic, interactive and risk-free environment for skill acquisition (Martínez-Gutiérrez et al., 2023). In one article this was demonstrated through the development of a VR-based digital twin of a bioreactor, which enabled immersive training on both routine operations and rare abnormal events, including real-time feedback and error management in a safe environment (Hassan et al., 2024). In another study, a VR-based digital twin system was compared with real equipment training, where it was shown that the trainees using VR improved their performance by 38%, nearly matching the 47% improvement shown in real equipment training and outperforming 2D computer-based training which only scored 28% (Martínez-Gutiérrez et al., 2023). This indicates that immersive digital twin environments can support effective skill transfer to the physical workplace.

Digital twin technology has therefore become increasingly important in industrial contexts, especially with the transition toward Industry 4.0 and Industry 5.0 (Martínez-Gutiérrez et al., 2023). Digital twins can support more agile and resilient operations by enabling scenario planning and virtual testing to reduce costs and improve quality, as highlighted in the industry report by McKinsey & Company (2024b). They allow manufacturing companies to move from reactive to predictive operations, enhancing productivity and decision-making in product development, production planning, and maintenance (Attaran & Celik, 2023). The market for digital twin technology is expected to grow 60% annually over the years 2024 to 2027, reaching $73.5 billion by 2027 and approximately 70% of C-suite technology executives already express interest or actively invest in digital twins. These trends, highlighted in the industry report by McKinsey & Company (2024b), indicate the technology's strategic importance for industrial transformation.

2.5.3 VR

Virtual Reality (VR), or virtual environment (VE), is a computer-generated environment in which the user is experiencing being in a particular location, different from the physical environment where the user is (Wickens et al., 2013). In a virtual environment, the user does not only passively view, but can further interact with and manipulate the environment, distinguishing it from e.g., watching a movie with computer-generated imagery. VR can create a sense of presence and immersion in which the user feels like they are being "inside" in the virtual world. A virtual environment consists of multiple features, each contributing to the experience of a real environment and sense of presence and immersion. These features are: three-dimensional viewing (the environments space is presented in 3D, often enhanced with stereopsis), dynamic motion (instead of static images, scenes update continuously as the user moves or interact with the environment), closed-loop interaction (meaning there is little to no lag between an action being initiated until the resulting motion occurs), ego-centered frame of reference (the environment is presented from the point of view of the user), head/eye motion tracking (having the user's view of the environment correspond to the head motion as it would in the real world), multimodal interaction (interpreting the environment with multiple senses and having the VR-system generate this e.g. by auditory feedback and force, and tactile feedback using haptic gloves or force-reflecting joysticks), and interactive objects and agents (which can be manipulated or interacted with).

One area where VR has proven highly effective is in training applications, especially when tasks are expensive or dangerous to train in a real environment (Wickens et al., 2013). However, the use of VR does not come without challenges. One of them is cost and thus, the benefits of more immersive and large-scale environments need to be well established to justify larger expenses. Another challenge with the use of VR is lag. The lag does not need to be great to have a considerable impact on the users' feeling of presence or effectiveness in a multiuser collaborative environment. To combat lag, however, the imagery being rendered during motion can be simplified since it is more important to have accurate motion in the environment than high resolution. A third challenge is biases and distortions, but these can be eliminated through proper calibration. A fourth challenge is lostness and disorientation, which can be a problem if the virtual environment is large. A solution to this is to include a map or compass in the field of view, but consideration needs to be taken to the detail and resolution of these to be readable. A final challenge is cybersickness where the user feels nausea, dizziness, or disorientation due to lag or a mismatch between head movement and display movement.

2.5.4 Cobots

Collaborative robots, commonly referred to as cobots, are engineered to operate in collaboration with human workers within shared workspaces, eliminating the need for physical barriers (Sultanov et al., 2022). Unlike traditional industrial robots, cobots are equipped with advanced safety mechanisms, tactile sensors, and adaptive programming, making them suitable for tasks that require close human-robot interaction (Arjomandi & Mukherjee, 2026).

The use of cobots has increased in welding, additive manufacturing, and manufacturing (Arjomandi & Mukherjee, 2026). Typical use cases include assembly where the robot can act as a third hand to lift and hold parts while the operator performs assembly tasks (Safeea et al., 2019) but also for taking over tasks that are hazardous, repetitive and strenuous, increasing accessibility for disadvantaged workers while also reducing the risk of harm (Eimontaite et al., 2022).

According to Semeraro et al. (2024), cobots support learning by creating a safe, interactive environment where workers can practice tasks directly with the robot. By reducing cognitive workload and improving predictability, cobots allow workers, especially those with limited robotics experience, to build skills gradually as the robot assists and mediates the task. On the other hand, Dornelles et al. (2023) means that cobots rather help workers perform their tasks more efficiently and engage them in higher-level activities that involve cognitive, decision-making, and supervisory skills. From this perspective, cobots are not explicit upskilling tools but instead create indirect opportunities for workers to develop and use advance skills.

Cobots still come with multiple constraints regarding human-robot interaction. While they might reduce physical ergonomic strain, they can introduce cognitive and fatigue-related loads (Arjomandi & Mukherjee, 2026). Operator resistance is also a barrier, often driven by low trust and fears of job displacement (Arjomandi & Mukherjee, 2026). Furthermore, cobots currently lack natural communication modalities such as gesture and voice-based interaction, meaning that operators still require a certain level of robotics expertise (Arjomandi & Mukherjee, 2026). Lastly, although cobots typically require lower initial investments than traditional robots, they still demand substantial integration costs for sensors, tooling, programming, and workspace adaptation (Arjomandi & Mukherjee, 2026).

2.5.5 Artificial Intelligence

Artificial Intelligence (AI) is a branch of computer science focused on creating systems that can perform tasks that usually require human intelligence. These tasks include reasoning, learning, problem-solving, and decision-making. This definition is also reflected in industry reports by McKinsey & Company (2024a).

One of the most significant ways AI can support upskilling is through personalized and adaptive learning systems which tailor training pathways to the needs, strengths, and goals of each learner (Espinoza, 2025). AI systems can analyze performance data and learner behavior to adjust content difficulty, recommend modules, and provide real-time feedback that helps them develop the necessary skills. Furthermore, AI can be leveraged to identify and address skills gaps within the workforce. By analyzing employee performance data, job requirements and industry trends, AI can pinpoint where skill shortages exist and suggest where training is needed (Espinoza, 2025).

The integration of AI into education also faces constraints. Both learners and educators' express resistance towards AI, due to concerns of job displacement or doubts of its effectiveness. Learners, especially for older generations, might feel AI tools intimidating, while educators worry that relying too heavily on AI risks reducing the human interaction, which might be necessary for motivation and engagement in learning environments (Espinoza, 2025).

2.5.6 Smart Gloves

Smart gloves are wearable devices equipped with advanced sensors and microcontrollers that detect and analyze hand and finger movements (Singh et al., 2024). They provide tactile feedback, making them useful for enhancing precision, supporting real-time monitoring, and improving user interaction in industrial contexts. In manufacturing contexts, for example, smart gloves can be used for monitoring workers force exertion and providing immediate feedback when certain tasks are done in a non-ergonomic way, helping workers adjust their motions to avoid injury (Sharma et al., 2026).

Smart gloves could therefore function as training and upskilling tools. By providing immediate feedback on motion quality, force, and ergonomic posture, they can help workers refine motor skills which are essential for manual tasks. Real-time data collection would also enable instructors or automated systems to assess skill progression, identify high-risk movement, and intervene accordingly.

Research on smart gloves is still in an early stage of development. While there exist many prototypes, these are mainly focused on demonstrating feasibility rather than providing fully mature, ready for industry solutions. Current studies highlight promising capabilities, but they also note that today's designs often require refinement of large-scale deployment is possible (Sharma et al., 2026; Singh et al., 2024).

2.5.7 Serious Games

Serious games are games designed for purposes beyond the purpose of entertainment, with the main purpose being learning and education. Brauner and Ziefle (2022) describe serious games as a human-centric methodology that uses game environments to enable knowledge transfer, competence building, and skill assessment. The authors argue that serious games are constructivist learning tools that allow learners to actively engage with the learning material and as a platform for developing and testing ideas without real-world consequences. Conil et al. (2025) describe serious games as games that motivate learners through engagement, emotion, and social interaction which help them to learn without struggling.

Serious games have been shown effective to developing hard skills such as knowledge in supply chain management and safety for forklift drivers (Brauner & Ziefle, 2022) but can also be used for developing soft skills such as creativity in additive manufacturing (Conil et al., 2025). Brauner and Ziefle (2022) specifically argue that serious games are a viable method for re- and upskilling employees for Industry 5.0 and that they can be used for informing or raising awareness about certain topics, develop cognitive skills and training to perform certain tasks.

Serious games are, however, constrained by the nature of their design. Serious games must offer complex simulations for realism but be as simple to use as possible while fulfilling learning objects, a balance which can be hard to achieve (Brauner & Ziefle, 2022). Both articles also highlight that serious games require extensive iterative development, which can make them resource-intensive to design (Brauner & Ziefle, 2022; Conil et al., 2025).

2.5.8 Learning Management System

A learning management system (LMS) is a digital platform for developing, managing, and delivering courses, learning resources, assessments and provides a space for teacher and student collaboration (Madyatmadja & Wiputra, 2023). Core functions often include content management, assessment, feedback, and communication tools (Dahal & Manandhar, 2024). In education, LMSs are used to organize course material into modules, administer quizzes with feedback, and allow interaction through forums and messages. They can also integrate with other systems to streamline administration and reduce information duplication, like student information systems (Dahal & Manandhar, 2024). However, in many applications, LMSs are primarily used only as a file repository, with limited use of collaborative features, which creates a teacher-centered approach rather than a learner-centered (Alhazmi & Rahman, 2012).

The main benefit of LMSs is that they centralize access so all material, activities and grades can be accessed in one location, streamlining administration and the learning process for both students and teachers (Madyatmadja & Wiputra, 2023). The systems also allow for structured learning and resource management. Teachers can organize modules, roles, and deadlines, and monitor participation and task completion, while students follow consistent paths for submissions and feedback. Feedback can also be scaled through forums, messages, grades, which shortens feedback cycles and helps provide timely and constructive feedback, which is important for learning (Dahal & Manandhar, 2024). Lastly, LMSs support multiple learning methods like face-to-face, blended, and online learning, increasing flexibility, and allowing for implementation in different contexts.

As previously mentioned, one common drawback is the teacher-centered approach where the LMS is treated as a file repository. Interactive features exist but are not used due to LMS structure often being designed where teachers upload and students download, which gives students few opportunities to co-create material or engage (Alhazmi & Rahman, 2012; Dahal & Manandhar, 2024). Further constraints can also arise if users experience complex interfaces and confusing navigation paths which can decrease usability and increase the time and cognitive load required to complete tasks (Dahal & Manandhar, 2024).

2.5.9 Gamification

Gamification is the use of game design elements and principles like mechanics, feedback, and aesthetics into non-game contexts to increase engagement, motivation, and goal-directed behavior (Christopoulos & Mystakidis, 2023). In education, it is often implemented through digital platforms, and the aim of gamification is to improve perceived autonomy, competence, and relatedness of learners while also enriching the learning experience. Gamification should not be confused with serious games (full games with learning intent), as it only selects certain game elements which are included in existing activities and systems with the purpose of motivating users to use it.

According to gamification research, different core game mechanics can be mapped to learning activities and outcomes (Christopoulos & Mystakidis, 2023):

- Avatars/Personas can be used to enable safe role-play and strengthen empowerment and control in learning.
- Points provide easy-to-understand metric and immediate feedback when doing meaningful actions such as reaching milestones or fulfilling objectives.
- Turns allow progression to be segmented into distinct phases, allowing for planning and reflection.
- Levels are also segmented phases, but where the difficulty usually rises as the user passes certain checkpoints.
- Badges symbolize accomplishments when users reach certain targets and act as evidence of capability.
- Challenges bundle certain tasks that need to be completed to earn a reward or complete an objective and are usually associated with activities needing problem solving.
- Rewards can both be extrinsic (like badges, points and physical or virtual goods) but also intrinsic (like progress bars, notifications, and leaderboards) which can motivate long term engagement.
- Leaderboards visually show each user's rank relative to the others based on completed achievements.

When mechanics are mapped to learning actions and outcomes, gamification can raise motivation by making goals, progress, and feedback more noticeable, while avatars and badges can add social safety and act as evidence of competence. However, a reoccurring design failure in gamified learning is the overreliance on points, badges and leaderboards which is called "pointification" (Rapp, 2014) where extrinsic rewards become the experience rather than being used as tools in a broader motivational design, which could create shallow engagement and suffocate intrinsic motivation. Gamified learning experience should also combine richer mechanics like quests, levels and cooperation and try differentiating experiences for different learner profiles.

2.5.10 Microlearning

Microlearning is an educational approach where content is delivered in short and focused segments with the intent to learn specific knowledge and/or skills quickly (Ingram Nissen et al., 2023). Used right, microlearning can engage learners and foster quick comprehension (Ingram Nissen et al., 2023), and it has been showed that students exposed to microlearning had a positive knowledge assessment and generally higher scores compared to control groups' (Taylor & Hung, 2022). Engagement is achieved through action-oriented content that is also focused on the needs of the audience. Quick comprehension and retention are enhanced by content that is concise and easy to process (Ingram Nissen et al., 2023). Adding to these positive effects of microlearning, it may also lead to improved confidence among learners (Taylor & Hung, 2022), and it is easily integrated into learners' daily activities – thus supporting continuous learning (Muñoz-Repiso & Betancur Chicué, 2023). Microlearning is closely related to the term just-in-time learning, in which the criteria of presenting microlearning at the time of need for the learner to address a skill or knowledge gap is added (Taylor & Hung, 2022). Ingram Nissen et al. (2023) presents things to keep in mind when creating learning content, especially with microlearning, to achieve more memorable and effective content. These are:

- Reduce cognitive load – only include the most critical information since reduced unnecessary mental effort can help people to remember.
- Connect the content to what the learner already knows – it is easier to remember new information if it is connected to prior.
- Chunk content into meaningful segments – chunking content into manageable sections makes it more digestible. By sequencing these sections in a logical order, you help the learner form a mental schema.
- Format for the medium – people generally scan content and only read a fraction of the text, so use descriptive headlines and subheads, and bring up important messages early so the learner stays engaged.
- Use plain language – avoid jargon and acronyms and use short sentences with plain language used by the learner.
- Provide content in multiple formats – for some content, that may be more complex and not suitable to be simplified, it may be more appropriate to provide the learner with a simple concept acting as a cue to look up more complex information or procedure.
- Employing practice and feedback – testing learned knowledge is an effective method to promote learning and to recall information helps in retaining it in the long-term memory.
- Provide multiple, spaced opportunities – instead of introducing new topics and their related concepts all at once, it can be better to cover the topic over spaced segments.

There are however some limitations with microlearning as well, as discussed by (Ingram Nissen et al., 2023). One of them is the most obvious one – there is only so much that can be learned in a cramped period, and complex topics may not be suitable for the format at all. Because of the limited time, behavior change can be unlikely to be achieved with microlearning alone. Another limitation is that learners may lose sight of the big picture when focusing on one smaller task at a time and having trouble connecting new information to old and seeing dependencies. Microlearning is heavily dependent on technology which can thus act as a barrier for some learners to access the material.

2.5.11 Scenario-based training

Brown et al. (1989) argue that knowledge cannot be separated from the context and activities in which it is learned and used. Knowledge is situated, instead of abstract, and is typically learned through participation in real activities rather than just passively listening. One method to accommodate this claim is so called scenario-based learning (SBL). SBL is a learning method in which the learner is immersed into a specific realistic scenario that incorporates authentic challenges and circumstances like the ones found in the real-life setting (Errington, 2010). The scenarios can be developed further to promote active and interactive participation, which enhances understanding and retention of knowledge for the participant(s) (Saha et al., 2011).

Major benefits with SBL are the ability to learn skills and connect theoretical knowledge to practice by implementing them in a real-world scenario. The learner may also gain confidence in handling the real situation by being able to train in a safe and controlled environment and perhaps at a slower pace in advance than what is later expected. The environment and scenarios can also be tailored to the specific case and individuals which enhance relevance and effectiveness, and the immersive nature increases engagement and motivation among learners (Mehall, 2022). Prominent drawbacks of SBL do however include high development costs to make the scenario as realistic as possible, complexity to use, high instructor workload if it is human-guided, and limited scalability if it is dependent of physical attributes. Complex scenarios can also be overwhelming and create cognitive overload among learners, ultimately reducing knowledge acquisition (Shaheen et al., 2026).

3 Methodology

This chapter describes the methodological approach used to address the research aim of the study. It presents the research strategy and research design, outlines the research process, and explains the methods applied for data collection and analysis. The chapter also provides a rationale for the chosen methods and discusses their suitability.

3.1 Research Strategy

The research strategy is based on a qualitative approach. The focus on qualitative methods is motivated by the exploratory and forward-looking nature of the study, which seeks to understand how future skills and knowledge requirements emerge due to technological and organizational change. According to Bell et al. (2022), qualitative research is appropriate when investigating complex processes such as socio-technical systems where human behavior, perceptions, and learning are in focus.

3.2 Research Design

The study has followed an exploratory case study design of Volvo Cars' final assembly. This research design allows for in-depth investigation of future operator roles and competence requirements within their real industrial context. Furthermore, the case study design allows for flexible research methods such as participant observation and unstructured interviews, which can be helpful for generating valuable insights from operators, supervisors, and support staff (Bell et al., 2022). As previously mentioned, the design is exploratory as the study aimed to identify and structure emerging skills and knowledge, rather than testing predefined hypotheses.

3.3 Research Process

The research process is structured into five phases and illustrated by Figure 3.1.

The first phase consisted of a literature review. Relevant books, research papers, and articles related to Industry 4.0/5.0, human-machine interaction and workforce competence in manufacturing have been studied. Other relevant literature of interest has also been articles or papers related to learning, learning methods, and motivation. The literature review established the theoretical foundation of the study and is also used as input for the development of interview guides and analytical lenses used in the discussion.

In the second phase, empirical data collection within the case organization has been carried out through semi-structured and unstructured interviews, document analysis, and observations. This phase aimed to capture the current state of onboarding and learning in final assembly, anticipated future changes in roles and competence requirements and feedback on the prototype concepts.

The third phase consisted of data analysis and synthesis, where the collected data was analyzed using thematic analysis to identify patterns across interviews and observations. The analysis resulted in a synthesis of current learning challenges in final assembly, a set of design requirements for a proposed future state, and a proposed framework for future competence requirements for final assembly.

Based on the design requirements, the fourth phase focused on assessing and selecting learning concepts and technologies to solve the challenges identified in the current state of learning. A prototype was then developed to make the proposed concept tangible and to enable evaluation with stakeholders.

The fifth phase focused on evaluating the proposed concept. The prototype was discussed with relevant stakeholders and refined through feedback. Additionally, the prototype and its design choices were analyzed through the theoretical framework. Potential operational implications such as quality and cost were also assessed based on stakeholder input and empirical findings. The future skills findings were also analyzed through the theoretical framework.

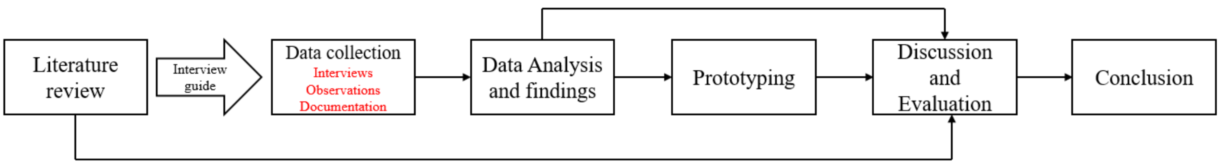

Figure 3.1: The research process.

3.4 Data Collection

To answer the specified research questions, this study has employed a qualitative data collection strategy using multiple sources. The methods used include a literature review, semi-structured and unstructured interviews, observations, and documentation analysis. Using multiple data collection methods allows the phenomenon to be studied from different perspectives and supports the validation of findings through data triangulation.

3.4.1 Literature Review

A literature review was conducted to establish a theoretical foundation for the study. According to Bell et al. (2022), a literature review is vital to understanding what is known about a topic, if there exist any clashes of evidence as well as helping to position the study within already existing knowledge.

The literature was gathered from academic databases such as Scopus, Google Scholar, Web of science and Chalmers library. Industry reports from organizations such as consultancy firms have also been used which can provide more detailed practical insights and applications of studied theories or phenomena. Searches were done on terms related to: industrial transformation (e.g., Industry 4.0, Industry 5.0), competence and skills (e.g., skill gaps, upskilling, reskilling) and learning and training approaches (e.g., cognitive load, microlearning, LMS, gamification, AR/VR/XR).

In Scopus, structured search strings were used. One example query applied in Scopus was:
TITLE-ABS-KEY ((“technology" OR "technologies" OR "tech" OR "innovation" OR "digital tools") AND (“operator" OR "worker" OR "employee" OR "staff”) AND (“upskill*" OR "skill development" OR "training" OR "education" OR "learning”) AND (“manufacturing" OR "production" OR "industrial" OR "factory”))

The literature review followed an iterative approach. Initial searches were used to identify publications and establish key themes. These themes later guided targeted searches and additional literature was identified through snowballing, such as reviewing references and citations (Wohlin, 2014). Screening of literature was done by reviewing titles and abstracts for relevance to the study (final assembly / manufacturing contexts, competence and learning and technological change). Full texts were then reviewed for those sources that were deemed to be relevant.

3.4.2 Interviews

To provide more nuances and insights to the study, semi-structured interviews have been conducted. The purpose of these interviews was to explore how skills and knowledge are currently developed, shared, and applied in final assembly, as well as identify challenges related to learning and knowledge transfer. The interviews also aimed to capture perceptions of future competence requirements and how learning needs may change. According to DiCicco-Bloom and Crabtree (2006), semi-structured interviews are widely used in qualitative research as they allow for flexibility by combining predetermined open-ended questions with questions that emerge during the dialogue. This flexibility allows the interviewer to explore respondents’ experiences in greater depth and to capture new insights and perspectives.

To align the empirical work with the study’s objectives, the interviews were conducted in three rounds with different purposes (see Table 3.1):

1. (Interviews 1-13): These interviews focused on understanding the current state of learning in the final assembly as input for RQ2.

2. (Interviews 14-19): These interviews focused on anticipated technological and organizational development and their effect on future skills, roles, and competence needs as input for RQ1.
3. (Interviews 20-25): These interviews were conducted to gain feedback on the prototype concept. Three of these participants were operator who had previously also participated in the first round as these persons were identified to being engaged and interested in the study but also to support comparison between current state and envisioned future state. A fourth interview was conducted to provide a leadership perspective. An additional fifth interview was done with a XR team at Volvo Cars to investigate what options there are for XR and how feasible the technology is for final assembly training as well as getting input on the prototype. This interview round acted as input for RQ2 (and indirectly RQ3 through perceived operational implications).

#	Role	Main RQ supported	Date
1	Operator	RQ2	2026-02-27
2	Operator	RQ2	2026-02-27
3	Operator	RQ2	2026-02-27
4	Operator	RQ2	2026-02-27
5	Operator	RQ2	2026-03-04
6	Operator	RQ2	2026-03-04
7	Mentor	RQ2	2026-02-27
8	Mentor	RQ2	2026-03-04
9	Plant Academy instructor	RQ2	2026-03-05
10	Plant Academy instructor	RQ2	2026-03-06
11	Plant Academy instructor	RQ2	2026-03-06
12	Plant Academy manager	RQ2	2026-03-06
13	Plant Launch supervisor	RQ2	2026-03-06
14	Manufacturing engineer	RQ1	2026-03-09
15	Manufacturing engineer	RQ1	2026-03-16
16	Manufacturing engineer	RQ1	2026-04-08
17	Shop manager	RQ1	2026-03-25
18	Former plant manager	RQ1	2026-03-31
19	Advanced Technology & Innovation Lead	RQ1	2026-03-17
20	XR team	RQ2	2026-03-24
21	Global Learning	RQ2	2026-04-27
22	Operator	RQ2 (+ indirect RQ3)	2026-04-27
23	Operator	RQ2 (+ indirect RQ3)	2026-04-27
24	Operator	RQ2 (+ indirect RQ3)	2026-04-27
25	Team Leader	RQ2 (+ indirect RQ3)	2026-04-27

Table 3.1: List of interviews conducted.

Unstructured interviews have also been held spontaneously as opportunities arise, for example during observations or informal discussion in the production environment. These interviews were intended to capture contextual insights, clarifications, and reflections that may not emerge during scheduled interviews and to complement the semi-structured interviews by providing additional depth to the data collection.

Purposive sampling has been applied to identify interview participants with relevant experience and insight into final assembly operations. This approach allows for intentionally selecting respondents who are well positioned to contribute to the research questions (Bell et al., 2022). Purposive sampling is considered appropriate, as it supports the collection of detailed and contextually grounded rather than statistically generalizable results, which also is the aim of this thesis.

3.4.3 Observations

Observations were used as a complementary data collection method to gain contextual understanding of work practices and learning situations in the final assembly to answer RQ2 (see Table 3.2). The observations were limited in scope and were primarily intended to support and contextualize interview findings rather than constitute an ethnographic study.

The study combined non-participant and participant observation. Non-participant observation was carried out to observe learning situations in the context (for example mentor-operator interaction, use of work standards and support systems and daily learning routines), for convenience these were conducted in connection with the interviews conducted in final assembly. Additionally, participant observation was conducted by taking part in activities learning conditions first-hand. This included spending one day working on the line as operators and going through parts of the onboarding process.

#	Description	Date
1	Onboarding (Introduction)	2026-01-22
2	Onboarding (Basic skills training)	2026-01-23
3	Skill training online	2026-02-05
4	Visit in final assembly	2026-02-27
5	Visit in final assembly	2026-03-04
6	Onboarding (Simulated Work Environment training)	2026-03-13
7	Visit in final assembly	2026-03-25
8	Visit in final assembly	2026-04-27

Table 3.2: List of observations.

3.4.4 Documentation

Internal documentation was reviewed to provide insight into descriptions of competence requirements, training approaches, and learning related routines in the final assembly. The reviewed material included internal onboarding and training documents, standardized work instructions, and other learning related documentation used in daily work. These documents, together with the observations and interviews, were used to establish the current state of learning and to allow comparison between intended state versus actual state.

3.5 Data Analysis

The collected data has been analyzed through thematic analysis. This approach is widely used in qualitative research and is a common method for identifying, analyzing, and reporting patterns within data. Thematic analysis offers a flexible framework that allows researchers to organize and interpret complex datasets, which provides rich and detailed descriptions of the data (V. Braun & Clarke, 2006). It involves systematically coding data, searching for themes, and then reviewing those themes to ensure they accurately reflect the data's meaning. Given the exploratory research design of the study, an inductive approach was found to be a suitable approach. An inductive approach allows the researcher to let the data determine the themes, compared to a deductive approach where the researcher analyses the data using predetermined themes based on theory or other preconceptions.

According to V. Braun and Clarke (2006) a thematic analysis follows the following steps:

1. **Familiarization**
   Getting familiar with the data. Transcribing audio, reading the documents to get familiar with it.
2. **Coding**
   Sentences and phrases are coded by highlighting them with different colors and giving them short labels to describe the content.
3. **Generating themes**
   Patterns are identified among the codes and by combining several codes, themes can be found.
4. **Reviewing themes**
   Themes are reviewed against the collected data to make sure they represent the findings. In this stage themes can be split up, combined, discarded or new can be created to make them more usable and accurate.
5. **Defining and naming themes**
   Involves naming the themes in ways that helps understand the data.
6. **Writing up**
   Summarizing the data and writing the report.

In practice, the analysis was carried out iteratively by both authors. Interview notes, observation notes, and relevant internal documents were first read several times to gain familiarity with the material. Initial coding was then conducted by assigning short labels to segments related to future skill needs, learning challenges, work-context constraints and improvement opportunities. The coding was done manually by highlighting and commenting in the material. The authors then compared and discussed the initial codes and grouped related codes into broader themes. When interpretations differed, the raw material was revisited, and codes or themes were refined until agreement was reached. In the final stage, themes were reviewed against the collected data and adjusted through merging, splitting or renaming to ensure that they represented the empirical data and supported the research questions.

3.6 Prototyping

Prototyping was used as a method for making the proposed future training concept (RQ2) more tangible and easier to evaluate and communicate. The prototype in this thesis functioned as a proof of concept rather than a final product; it was used to translate the insights from the literature about theories of learning together with findings from the interviews regarding the current onboarding. Some functions were implemented in a demonstrable form, while others remained conceptual and are discussed as future development possibilities.

The prototyping followed the Incremental Prototyping Method (IPM) (Butter et al., 2014), where an initial version was created and improved through cycles of feedback and improvement, allowing the prototype to evolve based on input from relevant users. Input was gathered continuously throughout the project in a less structured manner, e.g., through informal interactions in connection to interviews and observations. Toward the end of the study, a dedicated feedback session was held with 4 stakeholders to collect more focused feedback on the usefulness and fit with the shop-floor constraints.

For the prototyping, an AI-based tool called Lovable was used to rapidly generate and iterate a working prototype through prompts. Lovable was chosen because it enables fast iterations and the ability to roll back to previous versions, which fits the exploratory research design where the prototype serves for demonstration rather than being a ready-to-use product. To improve clarity and flow, the results chapter presents the final prototype state rather than reporting each version in detail.

3.7 Ethical Considerations

To make sure that the study follows ethical standards for business research, four key ethical guidelines have been followed as outlined by Bell et al. (2022): avoidance of harm, informed consent, privacy, and preventing deception. Participation in the study has been voluntary, and all participants were informed about the purpose of the study and how the collected data was used. Informed consent was obtained before the data collection, and participants have had the opportunity to withdraw at any time. To protect privacy, interview data has been anonymized, and no information that could identify a participant has been disclosed.

4 Results

This chapter presents the findings from the study. First, it summarizes the results related to future skill needs in the final assembly and introduces a competence framework developed from the data. Secondly, it describes the current state of learning based on interview findings, supported by observations and documents. Lastly, the chapter presents a proposed future state for learning and a prototype.

4.1 Required Skills in the Future

This section presents the results related to RQ1 where skill and knowledge requirements are expected to become increasingly important for the final assembly. The results are based on interviews with plant management and manufacturing engineering (ME) and focus on how technological developments are expected to influence roles and competence demands in the factory.

4.1.1 Anticipated Changes in Final Assembly

During the interviews, all interviewees agree on a continuous development toward more automation and digital support, however, they do not agree on how far this will go in the coming 5–10 years. Some describe automation as mainly an add-on that can help in certain areas while others expect a bigger shift where fewer traditional operators are needed, and work becomes more technology- or system-oriented.

A shared view across all interviews is that the final assembly is hard to fully automate. The work often involves variation, fine-motor skills and small "everyday deviations" that humans can handle quicker (e.g., adjusting soft parts like mats or fixing minor fitment issues). Even if automation increases, the interviewees expect that manual craft work will remain for complex and variable tasks.

Even if the views differ on the degree of automation, the interviews highlight several technological developments that are likely to become more present:

- Automation where it clearly adds value such for heavy, repetitive, and standardized tasks, in many cases motivated by better ergonomics for the assembler (e.g., wheel mounting or adhesion of components to inner roofs).
- More AI/vision-based quality checks where camera systems help detect errors faster and more consistent than manual inspections.
- More digital monitoring in the background, such as systems generating status

reports, alarms, and performance information, meaning that attention will shift towards interpreting and responding to system signals.
- More AGV/AMR solutions in logistics as systems mature and costs come down, which affects how material is moved and supported around the production lines.

4.1.2 Anticipated Role Changes

For assembly operators, several interviewees state that the manual assembly work will remain, particularly for steps where fine-motor skills and handling of variation are required. The interviewees also describe that some tasks will likely be supported by automation, especially for tasks where the work is heavy, standardized, or repetitive. The interviewees have different views on how much they expect the role to change. One view is that the operator's core duties will remain broadly the same even as technology increases around the line, whereas another view is that fewer operators will be needed, and the roles remaining will require a higher level of skill. One interviewee saw a shift from traditional assembly work towards more machine-operator like responsibilities, implying increasing need for automation related competence for remaining roles. Additionally, the interviewees expect that operators will increasingly work with digital support systems and improved guidance, like improved ways of presenting specifications and instructions compared to current paper-based material. The interviewees believe that problem-solving will remain central in the assembly work, and that logical thinking will be important regardless of whatever tools are used. One interviewee also raised concerns related to AI-enabled support, meaning that as AI becomes more common, employees need sufficient foundational understanding to evaluate outputs rather than just relying on answers they do not understand.

There is a clearer consensus that maintenance and technical support roles will become more technically demanding, especially from a digital standpoint. One interviewee stated that there will be a greater need for "good troubleshooters" regarding digital solutions and that the maintenance area will become more technical and engineering oriented as a result. Additionally, another interviewee highlighted a role distinction that already exists today; assembly operators can perform defined tasks without understanding the full product system whereas technical problem-solving functions require deeper system understanding to diagnose and resolve faults. The reasoning is that over the next 5–10 years, these technical roles will require even stronger competence in digital systems and connected production environments, as automation and digital monitoring increase, as well as the product itself becomes more technologically advanced and connected. From a ME perspective, an emerging competence challenge is described where mechanically strong profiles lack digital competence while more software-oriented profiles instead lack mechanical understanding, indicating a need for combined perspectives in roles or teams working with troubleshooting and development of digitalized production systems.

The interviews also point toward a growing need for roles that can handle automated systems more effectively. As lines increase their robot density, it becomes valuable to have people close to the line who can reprogram or adjust robots when new models are introduced, instead of relying on external suppliers. The interviewees also describe that the factory will require stronger competence to understand and manage connected production systems as digitalization increases.

The interviewees also highlight increasing use of AI/vision systems for quality control, where camera-based systems can detect deviations and errors more consistently than manual inspectors. This implies that quality-related work will become more central around interpreting and acting on system inputs.

Beyond the line, an increased use of AGV/AMR solutions is expected as these mature and become more cost-effective, implying increased interaction with automated material handling around the lines.

Lastly, the interviewees also highlight that in areas where humans remain part of production, leadership and people-related aspects will remain relevant. One interviewee emphasizes EQ and the ability to work with people continues to matter in the factory and cannot be replaced by AI.

4.1.3 Competence Framework

In Section 4.1.1 and 4.1.2, the anticipated technological development and role changes were described. To answer RQ1 in a structured way, these findings were summarized into a competence framework (see Table 4.1) for future operators in the final assembly. In this framework, the competence categories within the competence framework are explained, and baseline and advanced levels of competence are defined. The scope of the study is to investigate what future skills operators will need, but to support further discussion, the competence areas will also be mapped to specialized/technical roles (maintenance, manufacturing engineering, etc.).

The competence framework was primarily developed through thematic analysis of the interviews conducted for RQ1, but some competence areas were also theoretically informed. In the first step, interview statements concerning anticipated technological developments, role changes, tasks demands and competence needs were coded. In the second step, related codes were grouped into broader competence themes. In the third steps, these themes were improved into the final competence categories presented in Table 4.1. Examples of how this analysis took place are shown in Table 4.2.

All identified competence categories were considered relevant for both operators and specialized/technical roles. The framework should not be interpreted as showing that some competencies belong only to a certain role, but instead the required depth. Baseline competence refers to the minimum combination of relevant skills and knowledge needed for stable performance of the production system while advanced competence is a deeper level of capability. The distinction between baseline and advanced levels, and between the expected competence depth for different roles, was based on how the interview respondents described where the competence needs to be available, how frequently it is likely to be needed and whether it is required directly in day-to-day shop-floor work or mainly in more specialized support and development functions.

Competence area	**Baseline (B)**	**Advanced (A)**	**Operator**		**Specialized roles**	
			B	**A**	**B**	**A**
Manual and procedural assembly skills	Standardized work (OIS/WES), quality judgment through tactile and visual feedback, manual dexterity	Adaptive task execution during deviations, contribution to standardized work		x	x	
Digital literacy	Use of digital interfaces, understanding of production data	Interpretation of alarms and data trends, identification of deviations in system behavior	x			x
System understanding	Understanding how manual work and automated systems interact, adjusting or resetting systems	Diagnostic understanding of systems	x			x
Problem-solving and troubleshooting skills	Identification of deviations and correct escalation, logical reasoning, root-cause analysis	Troubleshooting across mechanical and digital domains		x		x
AI literacy	Understanding purpose and limitations of AI systems, questioning outputs	Analytical evaluation of AI outputs, improvement of AI-supported processes	x			x
Social and collaborative skills	Teamwork, communication, feedback	Mentoring, leadership		x	x	

Table 4.1: Competence framework for future final assembly.

Example interview statement	Initial code	Interpreted competence implication	Final competence category	Support in literature
Manual work remains for variable tasks and fine adjustments	Human adaptability	Continued need for quality-by-feel and procedural execution	Manual and procedural assembly skills	Primarily emphasized in interviews, (Nahavandi, 2019)
Operators will increasingly need to interpret alarms, digital information, and system signals	Digital monitoring	Ability to understand and act on digital interfaces and system states	Digital literacy	(Gorecky et al., 2014; Hecklau et al., 2016; Romero et al., 2016)
Future production system will consist of more interacting systems	Increasing complexity	Ability to understand how systems interact	System understanding	(Gorecky et al., 2014; Hecklau et al., 2016; Romero et al., 2016)
Increasing levels of automated systems demand people closer to the line who can resolve issues	Problem resolution	Ability to diagnose and solve issues across systems	Problem-solving and troubleshooting skills	(Gorecky et al., 2014; Hecklau et al., 2016; Romero et al., 2016)
AI will be used more, but outputs must be understood and questioned	AI support	Understanding how AI behaves and its limitations	AI literacy	Primarily emphasized in interviews, (Nahavandi, 2019)
Increasing complexity will require more teamwork	Teamwork / mentoring / leadership	Importance of social and collaborative competence	Social and collaborative skills	Primarily emphasized in interviews, (Hecklau et al., 2016)

Table 4.2: Example of how interview findings were synthesized into the competence framework.

The competence framework makes up the thesis' answer to RQ1. Rather than predicting a fully automated final assembly, the findings show a hybrid competence profile where manual and procedural skills remain important but are increasingly complemented by digital literacy, system understanding, problem-solving skills, AI-literacy, and social-collaborative skills.

4.2 Current State of Learning in Final Assembly

Sections 4.2 - 4.7 address RQ2 by analyzing what kinds of training and competence development approaches are suitable for final assembly. The analysis starts from the current state of learning in the final assembly, followed by identification of key learning challenges and then formulation of design requirements. These requirements then guide the selection of learning concepts and enabling technologies, which are brought together in the proposed prototype.

In this section, the current state of learning in the final assembly is described. In this thesis, learning is divided into three parts: onboarding training for new operators, training related to new models or process changes, and continuous day-to-day learning.

4.2.1 Current State of Onboarding

The onboarding of a new operator at Volvo Cars follows the global instruction of Operator Readiness, which standardizes training and development activities across all plants. The process consists of six steps, a preparatory administrative Step 0 followed by Steps 1-5, that together ensure each team member has the competence needed to build customer parts or cars. This section will present the results from the conducted interviews, document analysis, and observations using each step of this onboarding process – all of which is relevant to answer RQ2.

4.2.1.1 General Introduction to Volvo Cars (Plant Academy)

Step 1 consists of a general introduction to Volvo Cars and the plant, including rules and regulations as well as practical information on working hours and time reporting. This step also aims to set the right mindset, culture and discipline and introduce concepts such as VCMS (Volvo Cars Manufacturing System), Lean principles such as 5S, and Muri, Muda, Mura. Furthermore, it introduces basic safety and basic knowledge to how Volvo works with the environment as well as labor union information. Step 1 takes one day to complete.

The interviews show that the introduction participants understand and appreciate the purpose of the introduction but that there is a clear gap between what is taught and how the work is carried out in practice. Several operators expressed that the first day contained too much information, too much repetition and too little practical relevance to their upcoming role in production.

One recurring experience was that the introduction was highly lecture based and repetitive and that there was an information overload, where more content was presented than realistically possible to learn: “It was good and fun, but too much information at the same time”, “The information is important, but you can’t remember everything because it was too much at the same time”.

Another recurring insight is that the theory was partly disconnected from the actual assembly work. One operator said that much of the content like work environment and culture “was a bit fluffy” and lacked relevance to their coming work role. Several expressed that they anticipated more practical elements already the first day and were surprised that the lectures accounted for that much time. While some element, such as company history and safety, were appreciated, many felt that the introduction did not sufficiently explain basic operational concepts such as andon, takt time, car specification, interpreting information screens, and other terminology (“lingo”) that later proved essential on the production floor, for example through examples to understand their practical relevance in production. This view was also supported by one of the educators at Plant Academy who thought that the current lectures lack a clear common thread: “Directly after something has been explained theoretically it should be possible to show it in practice, blending what has to be explained with something fun and concrete", but something the current education format does not allow.

4.2.1.2 Production Introduction (Plant Academy)

Step 2 aims to prepare employees for joining production with the purpose of setting a risk awareness, train the operators in basic skills (repetitive tasks, tool usage, ergonomics) and validating the employee's abilities of operational tasks for one day's duration. The operators also participate one day in a Simulated Work Experience (SWE) where a production environment is simulated, and wooden cars are built. The purpose is to learn how to work safely and as a team in production and to learn the basics of andon, real-time management, continuous improvement, and quality. The operators generally perceived the practical part of the introduction at Plant Academy as more helpful and engaging than the first theoretical day. However, they also described several limitations in terms of realism, depth, and alignment with the actual production environment.

Many interviewees said that the basic skills training which included screwing, plugging, repetitive tool use and ergonomics, was one of the most useful parts of the introduction. One operator described these exercises as "more serious" and appreciated having to complete them within a set of time, which helped get a taste of the expected pace in production.

However, several operators noted that practical training did not go far enough. One common desire was to have more time with the basic skills of stations and for the exercises to more closely reflect the physical demands and constraints of the real production line. For example, moments involving force, difficult angles, and handling tight or stiff components were not represented during training at Plant Academy. One operator explained that the practice moments were "small things, not the kind of force required on the line" and that this gap made the first days on the line more challenging.

The simulated work environment (SWE) also received mixed opinions. Some operators found it beneficial to try assembling wooden cars and practice basic flow, teamwork, and quality checks. Others meant that the simulation lacked realism, complexity, and urgency, resulting in a weak transfer of learning. One operator said that the SWE did not resemble the real work environment and only involved one single moment rather than the multiple interconnected tasks required on the actual line. Another operator commented that SWE "did not give the feeling of how the production line actually is," and that important aspects such as takt time, time pressure and decision-making under stress were largely absent. One of the educators at PA also noted this "the SWE training is compressed, and the stations are shorter due to cost reasons," thus does not fully replicate the real system.

Interviewees similarly noted here as well as in step 1 that it did not prepare operators for the organizational systems they would encounter in production like andon, takt time, information screens, and reading car specifications. These topics were either not included or only touched upon within SWE and basic skills training.

According to the educators, there is currently no structured or standardized method for verifying whether operators have acquired the intended knowledge and skills during the introductory training. One educator explained that "if the participant is engaged and participates, they get approved," indicating that completion is primarily based on attendance and visible engagement rather than any formal assessment framework. There is a form of "validation" connected to the SWE, which focuses on safety and quality. However, this validation appears to rely on the educators' qualitative judgment rather than on a defined assessment template.

4.2.1.3 Introduction to Plant & Shop

Step 3 involves introducing the new team member to the shop they are intended to work in (e.g., body, paint, final assembly etc.). The purpose is to learn about the shop's specific contributions, like main deliveries, KPIs, and organizational setups. This part should also cover the shop specific safety risks and should also be followed by an offline skill training to teach the mindset to follow standardized work and learn basics of quality, ergonomics, safety, and delivery. None of the interviewed operators reported having taken part in a structured plant- or shop-specific introduction as described in the official onboarding documents. Instead, their first contact with the shop environment occurred directly on the line through hands-on work with a mentor.

One of the mentors confirmed that an offline training station exists for their line, which is designed to provide a calm environment for initial skill development, but it is rarely used due to labor shortages and time pressure. She explained that although offline training could offer employees an opportunity to understand the basic steps of their stations without takt pressure, it is "never used" because "there is no time or available staff to bring the new employee to the station".

4.2.1.4 Introduction to Line & Station

Step 4 is the last training and development step for the new member, where he or she is introduced to the specific line and stations that will be operated. This step is also applicable if a current team member changes jobs within the shop to another team/station. The step includes an introduction to the team for the new member, so they feel included and become familiar with more social aspects of the work. Further, the step adds to previous safety instructions by applying them to the specific line/station, as well as introducing line and station specific guidelines, such as known risks with the mountings at the stations. In addition to this team and station specific introduction, offline skill training is supposed to be used to practice standardized work, learn how andon is used, and get up to pace with the operations in a safe way where mistakes can happen without consequences to online operations or customer cars. During this training, OIS and WES should always be used and fully understood to guarantee that the standard is followed. After this the new team member should conduct online skill training to gain confidence in the standardized work. This online training should be guided by a qualified team leader or team member and be executed through the online training four step model presented in Section 4.2.1.5. Rotation should also be restricted during this phase so that the new operator can focus on training at one station at a time.

However, the interviews indicate that Step 4 is not implemented as described in the model within the final assembly shop. Instead, the practice resembles Step 3 where offline training is rarely ever conducted due to a general shortage of personnel and time pressure, preventing the mentors from leaving the line to conduct structured offline training. As a result, new team members are instead introduced directly into the live production environment from the first day, learning under takt time and real operational conditions.

From the interviews, there does not seem to be a standard way of teaching a new station, but rather up to the mentor to teach how they see fit best. Some mentors are described as being very structured, patient, and pedagogical, while others are described as being highly stressed due to takt demands and unable to provide sufficient explanations, creating inconsistent learning conditions for new operators based on who happens to train them. The mentors also express concerns regarding the takt time: “you do not have time to double check while teaching and trying to keep calm,” “the tempo is the hardest part, no one is used to it.” The mentors should have completed a two-day course to be a certified mentor, but this course focuses more on how to welcome people and explaining pedagogically rather than exactly how to do the teaching.

Most new team members are introduced to a new station by first observing the mentor doing the operations while giving oral instructions on the steps as well as things to keep in mind regarding safety. Then the new team member successively tries the operations themselves while still receiving help from the mentor in a collaborative manner, all under live production conditions. This approach from observation to shared work to independent work is broadly consistent across the interviews.

A notable deviation from the intended onboarding design is the inconsistent use of OIS and WES. Although these documents should be the backbone of training, most mentors teach their way of doing the job including shortcuts, adaptations and personal techniques which sometimes diverge significantly from the standardized way of working. Most operators are therefore learning a version of the operation that differs from the standard way they are later expected to follow. Another deviation is that rotation is not restricted during step 4. Instead of training one station at a time, new members rotate like everyone else and are introduced to several stations early on.

After the new team member becomes gradually more independent in the operations, the mentors stop helping with the operations to just verify the results. Eventually the mentor moves away from the closest proximity and stays in the background as a safe line and support if needed. Then, when the new team member feels sufficiently confident with the operations (the guideline is two weeks) the mentor is removed and staffed as a normal operator again and the new team member is thereafter referred to use the andon system if help is needed in any way. Many new team members did however express that they did not feel completely confident in their work until several weeks, even months, later.

4.2.1.5 Verification of Capabilities

The last step (step 5) aims to secure operator readiness, i.e., that the operator has received sufficient training and development. The verification should verify the team members' capability of the assigned work tasks, and the operator should have gone through a minimum of 1000 cycles or 3 days with proper safety, quality, and delivery. This is verified through a document called Operator License Matrix. In this document, both the mentor and the operator sign off on each station once the operator is considered ready to work independently.

This document follows a four step model consisting of: (1) preparing the operator by reviewing risk information, operator instruction sheets (OIS) and work element sheets (WES), (2) demonstrating and walking through all work elements, (3) allowing the operator to practice selected activities, verify against the WES and gradually increase the speed and finally (4) following up through feedback, questions and checks against standardized work. This process is intended to ensure that the operator understands what the tasks are, how they should be performed, and why they must be performed in a certain way, and what the risks are with every activity.

According to the interviews and the observed practices in final assembly, this formal requirement to sign off each station in the operator license matrix is used but many operators complete the verification without fully understanding the underlying standardized work document or production support systems. As previously mentioned, many operators had not yet fully understood key operational concepts such as andon use, information screens or how to interpret car specifications and several operators reported that they had limited understanding of OIS and WES beyond the immediate task execution. One operator also mentioned that they have received limited information regarding how the team board functions, what the different documents mean, and how to perform offline tasks such as proactive operator and process study (POPS).

As a result, the signatures in the Operator License Matrix often reflect that the operator can replicate the observed assembly steps, rather than demonstrating a deeper understanding of standardized work, system interactions or the wider situational awareness required for independent and robust performance.

4.2.2 Plant Launch – New Model Implementation and Learning

Part of Plant Launch's responsibility when implementing a new car model for the plant operations is to prepare the workforce for the new product. This follows the Workforce readiness framework, and part of this is to train the workforce. In theory, this training in similar to Step 4 of the onboarding process for new team members resented in 4.2.1.4; the operator being trained is first trained offline to get comfortable and up to pace on the new operations and standard before being introduced to real customer cars online. During these steps, they are guided by a trainer from the Plant Launch Team and introduced to the OIS and WES of the new operations.

However, this training does differ from the onboarding process in many other ways. Firstly, the training involves all operators in the final assembly factory, and these are all trained by a limited number of trainers and thus a schedule is created for who to train when. This, in combination with deadlines for when real production is supposed to start, leads to insufficient training time for the operators. This was expressed by some interviewees regarding the training for the new EX60 model. Having a limited number of trainers for all operators also leads to less personalized and attentive training when online where multiple operators train at the same time since the whole line is staffed. Although the operators did not question the competence of the Plant Launch trainers, one operator noted that "the trainers aren't bad, but they are stressed, which makes their communication brief," highlighting that resource constraints affect the training experience.

From the interviews, it has come to light that the standards for the stations' operations have changed during the period of training for the new EX60. One operator expressed that "you are trained in one way, but then things change so it no longer applies." This has led to operators previously trained one way are not familiar with the new way of operating these stations according to the new standard which could differ by a range from smaller changes like which order to perform some steps in, to greater changes like completely new layout and machinery at stations. This in combination with deadlines for when real production is supposed to start leads to a stressed working environment where operators do not know if they are prepared or not.

4.2.3 Continuous Learning

Continuous learning in final assembly is not limited to formal onboarding or training initiatives but also relies on how changes and updates in daily work are communicated over time. To ensure that relevant new information is spread to affected operators, for example changes in company policies, changed work descriptions, changed standardized work or changes to team standards, Volvo Cars uses a document called "Information Sign-off". This is a physical paper document where new information is presented in a text format and often includes a describing picture. Attached is also a list of the affected operators together with a signature field where each operator needs to sign-off that they have read and understood the information. If some people were not present when the information was presented, they should receive the document next time they show up for work. Completed Information Sign-offs are then meant to be archived to allow follow-up on acknowledgment and coverage.

During observations conducted in the final assembly shop, several challenges related to the handling and usage of information sign-offs were identified. The documents were placed on the team boards and were often bundled in stacks containing several information sign-offs. In many cases, these documents showed signs of physical wear, for example damaged papers, folded corners, and sometimes missing pages. The condition of the documents made them difficult to read and suggested that they had been handled repeatedly over an extended period. Additionally, several documents had missing signatures, despite being months old. This indicates that coverage on all affected operators has not been achieved. Lastly, the observed handling of the documents made it difficult to get an overview of which information was actual and which was outdated. As documents accumulated over time, newer sign-offs were mixed with older ones.

To make operators aware of deviations and quality issues in daily operations, Volvo Cars uses error reporting. After each shift, all reported errors associated with the team are compiled into a list together with the station at which the error occurred and the name of the operator assigned to that station. The operators are expected to review the listed errors and sign to confirm that they have received and acknowledged the information. The purpose of the error reporting is to create feedback to the operators and support learning by making errors visible and traceable over time.

During observations, it was noted that these documents were often just handled as an additional administrative task rather than a learning activity. In practice, the operator often signed the documents without reviewing the listed errors. Also, no further dialogue between operators and team leaders was observed regarding causes of the reporting errors of potential learning points. The observations also did not indicate the existence of structured follow-up or targeted learning initiatives, for example, operators repeatedly associated with similar errors.

4.3 Identified Issues in Current State

This section presents the identified issues in the current state of learning in final assembly. The findings are based on interviews with operators, mentors and educators and supported by observations and document analysis. Based on the collected data, five challenges were identified and are presented below. The findings serve as the empirical basis for answering RQ2. The identified issues will later be used as design inputs for determining a more suitable learning approach for the final assembly environment.

4.3.1 Unclear Structure & High Information Flow

The interviews indicate that the onboarding process lacks a clear and consistent structure from a participant perspective. Even though the onboarding is formally divided into several steps, operators described difficulty in understanding how different training elements relate to each other and to their future work tasks. Several operators reported that large amounts of information were presented during the initial days, while connections to the upcoming practical work were limited. Concepts introduced early in training were often not presented again or demonstrated in practice, making it difficult for participants to understand their relevance at the time of learning. This perception was reported by several operators and was also confirmed during observations at Plant Academy, where training activities were heavily lecture-based and separated from later practical training on the line.

Similar challenges were identified in daily learning. New information and error reporting were communicated through multiple channels, primarily information sign-offs and error report lists. Observations showed that several information sign-offs were available at the same time on team boards, covering different topics and remaining visible over extended periods, making it difficult to distinguish new information from older. A similar pattern was observed in the handling of error feedback. Operators were expected to review and acknowledge lists of reported errors, but no structured linkage between reported errors, prior learning activities or follow-up training was observed.

4.3.2 Lack of Verification

Another identified issue concerns the validation of learning outcomes during onboarding. According to both operators and educators, verification focuses on participation rather than demonstrated understanding. According to the educators, the participants are generally approved upon completion of the scheduled activities without the use of standardized assessments. Interviews with operators indicate that completion of the onboarding process does not always correspond to a clear understanding of production support systems, standardized work documents, and other relevant information needed for daily work.

During continuous learning, the observations of information sign-off and error feedback processes showed that acknowledgment of information is shown through signatures, but the processes lack structured follow-up to verify understanding or behavioral change. The verification practices focus on confirmation of exposure to information rather than assessment of learning outcomes.

4.3.3 Limited Visualization and Resemblance of Real-world Operations

During onboarding at Plant Academy, operators described that production concepts were mainly presented theoretically, with few opportunities to observe or experience how these concepts work in the actual work environment. The practical parts of onboarding were generally experienced as more engaging than lecture-based sessions but were also described as lacking realism. Operators felt that the exercises did not fully reflect the physical demands encountered on the line such as force requirements and that they were simplified compared to real production, with limited representation of takt time pressure and decision-making under stress.

Similar limitations were seen in Plant Launch training, where offline training did not always correspond to final station layouts, equipment, or task sequences used during live production. Operators described those frequent changes to stations and standards during new model introductions that reduced the resemblance between training and online work.

4.3.4 Limited Resources and Time Constraints

Limited availability of time and personnel was identified as a constraint affecting training during onboarding. Interviews with mentors indicate that offline skill training is rarely conducted due to staffing shortages and production demands. During Plant Launch, similar challenges are described. A limited number of trainers are responsible for upskilling many operators within fixed deadlines, which results in compressed schedules and reduced opportunities for individual support. Observations indicate that time allocated for reviewing information sign-offs and error feedback is minimal, limiting opportunities for reflection and discussion.

4.3.5 Low Engagement

The interviews with operators indicated that engagement during onboarding varied depending on the training format. The practical elements such as basic skills training were generally perceived as more engaging than lecture-based sessions. The initial theoretical introduction at Plant Academy was often described as passive and difficult to stay focused on due to long sessions and high information density. Once entering live production, high tempo, and performance expectations constrained opportunities for active engagement in training. While the mentors were described as supportive, the takt time limited the possibility to ask questions or reflect during training.

4.4 Translating Onboarding Issues into Design Requirements

To move from problem identification to a solution design, the learning challenges identified in Sections 4.2 and 4.3 were translated into design requirements. The requirement sets are the first step in answering RQ2 as they define what a future training approach must be able to support in the context of the final assembly.

4.4.1 Requirement Set 1: Coherent Structure and Manageable Information Flow

1.1 The solution should present new information and content in small, easily manageable units with clear progression.
1.2 The solution should make learning pathways transparent and gather all learning activities within the same interface.
1.3 The solution should connect concepts to practical relevance.

4.4.2 Requirement Set 2: Verification of Learning and Readiness

2.1 The solution should integrate assessments that verify understanding of key concepts and procedures.
2.2 Verification should be traceable for managers and team leaders to enable follow-up and targeted support.
2.3 The solution should support rehearsal learning when issues occur.

4.4.3 Requirement Set 3: Improved Transfer and Contextualization

3.1 The solution should support contextual learning (i.e., learning in and near the work context).
3.2 The solution should support guidance for station- and line-specific knowledge (such as OIS/WES).
3.3 The solution should support safe training of critical sequences where possible without requiring production line time or excessive mentor involvement.

4.4.4 Requirement Set 4: Learning under Resource and Time Constraints

4.1 The solution should minimize dependence on resources (such as mentors and Plant Academy instructors) by supporting more self-directed learning.
4.2 The solution should not be too dependent on physical resources for training environments due to space and cost constraints.
4.3 The solution should fit within short time windows and support pause/resume.
4.4 The solution should reuse existing infrastructure to lower investment and adoption barriers.

4.4.5 Requirement Set 5: Engagement

5.1 The solution should provide visible progress.
5.2 The solution should use engagement mechanisms that reinforce meaningful competence development.

4.5 Selection of Learning Concepts

The requirement sets presented in Section 4.4 define what a suitable learning approach must be able to support answering RQ2. The purpose of this section is to translate the identified learning challenges and corresponding requirements into relevant learning principles concepts.

- Microlearning was selected to address R1 and R4 by enabling content to be broken down into shorter units that fit the shop-floor time constraints and reduce information overload.
- To address R2 practice testing was selected, i.e., using low stake assessments to make learning outcomes visible and enable early detection of knowledge gaps.
- Distributed practice (reinforcement over time) was selected as a supporting concept for R1 and R2 since it enables repeated exposure to information and rehearsal training.
- Gamification in the form of quests and badges was selected to address R5 to support motivation, but in a form which represents meaningful competence progress avoiding "pointification".
- Scenario-based training was kept as a concept for addressing R3, but it was recognized that highly realistic physical scenario training is resource intensive. Scenario-based training is therefore seen as something to be enabled through digital formats instead.

4.6 Selection of Enabling Technologies

While Section 4.5 identified learning concepts that could address the requirement sets, this section identified what enabling technologies that are needed to support those needs as well as addressing the requirement sets. The purpose is to show how the answer for RQ2 moves from the identified learning requirements into a practical and implementable solution.

From the literature review, a broad range of emerging technologies for training with potential to support operator learning and upskilling in manufacturing were identified. These technologies and concepts vary in maturity, purpose, and applicability to final assembly. The following technologies were initially identified as relevant in the study context: digital twins (DT), virtual reality (VR), augmented reality (AR), cobots, smart gloves, artificial intelligence (AI), and learning management systems (LMS).

The literature review also identified other interesting technologies: assisted reality, light- and voice guidance, industrial internet of things, eye tracking, positioning systems, humanoids, and remote maintenance support. These might be interesting for operator enhancement or assistance but given the scope of the study, these are not directly applicable for operator upskilling and were therefore excluded initially.

To narrow the set of the remaining technologies into a practical solution, the options were compared against the design requirements formulated from the empirical findings (R1-5). Priority was given to technologies that fulfil the onboarding needs, the need to work under takt-time conditions, reduce reliance on mentors and instructors and that are flexible and can be maintained as products and standards change. Based on the criteria, a LMS adapted for the work context was selected as the primary technology platform as it enables:

1. Structured learning paths and content management (R1) by organizing all learning content into packages/modules with visible progression and clear overview of required learning.
2. It can host embedded verification and traceability (R2.1 & R2.2) through quizzes and checks, completion tracking, and follow-up through manager dashboards. Additionally, it supports reinforcement and refresher learning (R2.3) by enabling scheduled or triggered refreshers linked to continuous learning activities such as information sign-offs and error feedback.
3. By delivering the learning in a digital format rather than physical lecture-based formats, learning can occur closer to the work context, reducing the time between learning and being exposed to key concepts and tools in production (such as andon) improving contextual learning (R3.1). Additionally, this also makes it easier to connect concepts to practical relevance (R1.3).
4. It supports resource-efficient learning (R4.1) as it allows for self-paced learning, reducing reliance on mentors and instructors. Additionally, the system can be adapted to fit within existing hardware within the factory, namely the tablets which are currently only used for rotation cards (logging which car has been built by which operator), mitigating some initial investment and reducing adoption barriers by placing the system where the operator already is working (R4.4).
5. Lastly, it can connect learning progression to quests and badges, supporting engagement and visible progress (R5).

To improve contextualization (R3.1 & R.3.2) without high deployment barriers, QR-based contextual learning was selected. By using this approach, physical locations, team boards, tools, or other points of interest can be linked to specific learning modules while requiring minimal additional hardware, supporting learning near the work context. Additionally, this approach supports verification (R2.1) as it allows to verify that the learner has for example located the nearest emergency exit or defibrillator by scanning QR-codes.

To address safe training of critical assemblies and sequences (R3.3) and use scenario-based learning in a scalable format, XR capabilities (AR/VR) were identified as a relevant future extension of the concept. AR can be used for providing guidance while learning assemblies where manual dexterity (touch and feel) is the most important learning factor, for example mounting cables requiring high levels of force or plugs requiring a certain technique. VR can be used for learning tasks where sequence understanding and decision-making are the more important learning factors. XR scenarios can be designed to be self-paced, meaning that operators can train in realistic scenarios without mentor or instructor involvement compared to the scenario-based training that exists today (R4.1), while also allowing assembly scenarios to combine physical and virtual objects, reducing the need space and material needed for training. Furthermore, XR has been shown to increase engagement and motivation as scenarios can be created to be interactive, supporting active learning (R5.2). However, AR/VR-based training was not implemented in the working prototype and remains a future development possibility.

To make the analytical chain from the findings in the current state to the proposed design more transparent, Table 4.3 summarizes how each identified issue is supported by evidence from the interviews, how the issue relates to learning theory, how they are translated into design requirements and how they are addressed through selected learning concepts and enabling technologies.

#	**Identified issue**	**Supporting evidence from current state**	**Related learning theory**	**Requirement set**	**Selected learning concept / technology**
1	Unclear structure & high information flow	Operators described the onboarding process as lecture-heavy, repetitive, and difficult to connect to practice. Information sign-offs and error feedback were also fragmented and difficult to overview.	(Mayer, 2017; Sweller, 2010)	Coherent structure and manageable information flow	Microlearning, Distributed practice, LMS
2	Lack of verification	Verification during onboarding was often based on attendance or signatures rather than demonstrated understanding.	(Dunlosky et al., 2013)	Verification of learning and readiness	Practice testing, Distributed practice, LMS, QR-based contextual learning
3	Limited visualization and resemblance of real-world operations	Operators described Plant Academy and SWE as lacking realism in force, pace, sequence complexity, and decision-making under stress.	(Martin et al., 2013; Wickens et al., 2013)	Improved transfer and contextualization	Scenario-based training, LMS, QR-based contextual learning, AR/VR-based XR scenario training (future capability)
4	Limited resources and time constraints	Offline training was rarely used due to lack of time and available staff. Mentors were often described as stressed and unable to provide sufficient support.	(Edmondson, 1999; Newman et al., 2017)	Learning under resource and time constraints	Microlearning, LMS, AR/VR-based XR scenario training (future capability)
5	Low engagement	Operators found practical training more engaging than lecture-based sessions. Long theoretical sessions and high tempo reduced opportunities for active engagement and reflection.	(Dunlosky et al., 2013; Edmondson, 1999)	Engagement	Gamification, LMS, AR/VR-based XR scenario training (future capability)

Table 4.3: Summary of selection process of learning concepts and technologies.

4.7 Prototype

The prototype presented in this section should be understood as the response to RQ2. Based on the identified learning challenges, the requirement sets and the selected learning concepts and enabling technologies presented in the previous sections, the prototype brings these parts together into one coherent proposal for how onboarding and continuous learning could be improved in final assembly. The prototype should, however, be interpreted as a proof of concept rather than as a production-ready or operationally validated system. In this prototype, the LMS structure, the main user views and the QR-based contextual learning function were implemented in a demonstrable form, while full AR/VR-based assembly guidance and scenario training were not implemented in the working prototype and remain future development possibilities.

The prototype developed in this thesis is a learning management system (LMS) which is adapted for use in the final assembly environment. The system is designed to run on the tablets already in use in Torslanda final assembly, where they are currently used for rotation cards i.e., logging the cars built on each station. To reduce the likelihood that the learning solution is overlooked in everyday use, the rotation card functionality is integrated within the LMS so that logging and learning-related activities are accessed through the same interface. Additionally, the prototype assumes that each line has one to two spare tablets that can be used specifically for onboarding and structured learning moments to reduce the need for operators to occupy station tablets or stand at active stations during training.

The purpose of the LMS is to consolidate all learning needs that occur during the operators' work life including onboarding, new model introduction, and continuous learning. The intent of integrating these activities is to provide a single place where operators can access required information, complete learning tasks, and get updates related to their daily work.

The system is divided into three views: an operator (public) view, a manager view, and a developer view. The operator view is the primary interface used in production and includes access to the rotation card (see Figure 4.1). Additionally, there is a button leading to a page for learning packages, where training content is organized into packages that are assigned or completed depending on operator need (see "A" in Figure 4.1 and Figure 4.2). There is also an area for receiving error reports (see "B" in Figure 4.1 and Figure 4.3) and informational updates (see "C" in Figure 4.1 and Figure 4.4). It also includes access to standardized work documentation (OIS/WES), to quickly retrieve instructions for the station they are operating (see "D" in Figure 4.1).

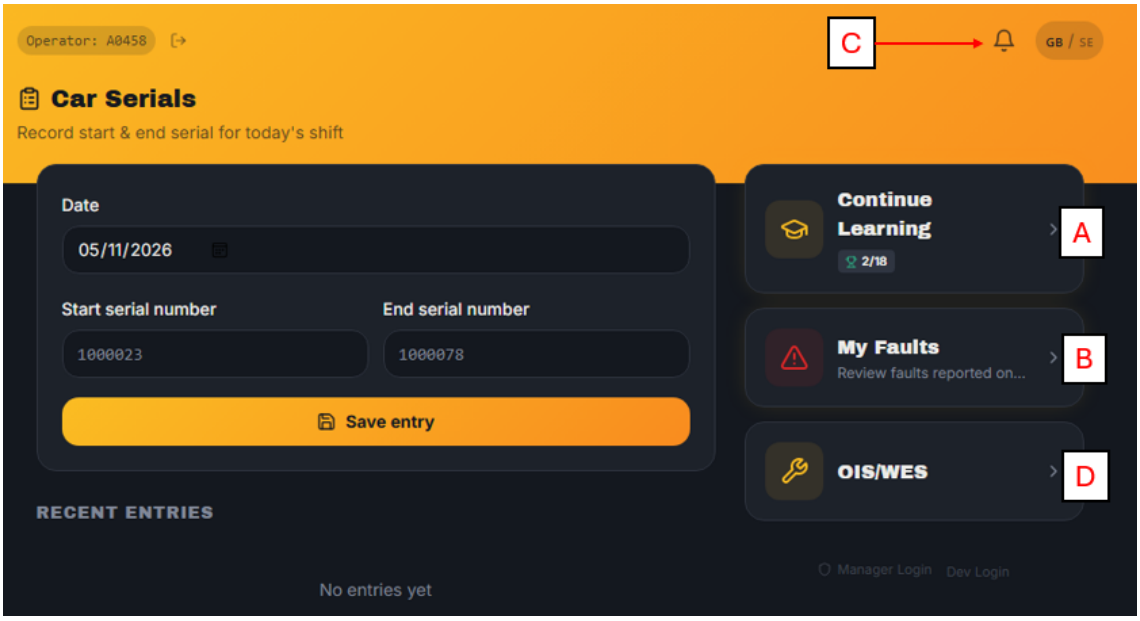

Figure 4.1: Landing page in the LMS.

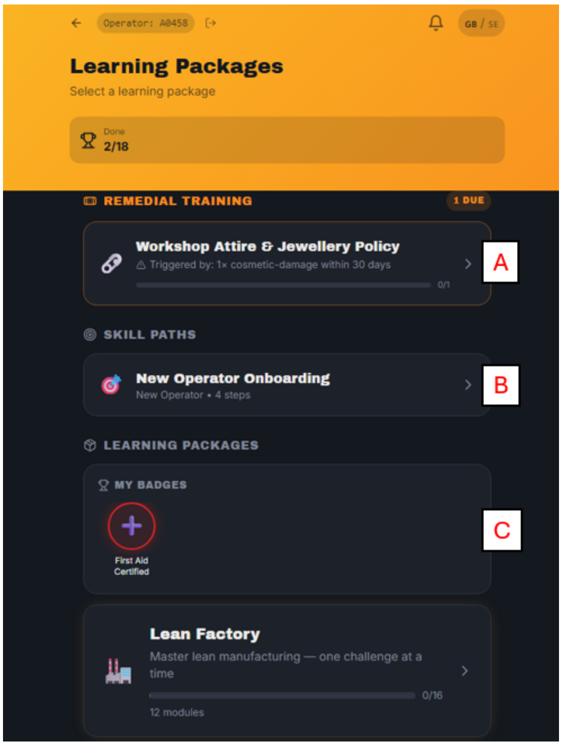

Figure 4.2: Learning page in the LMS.

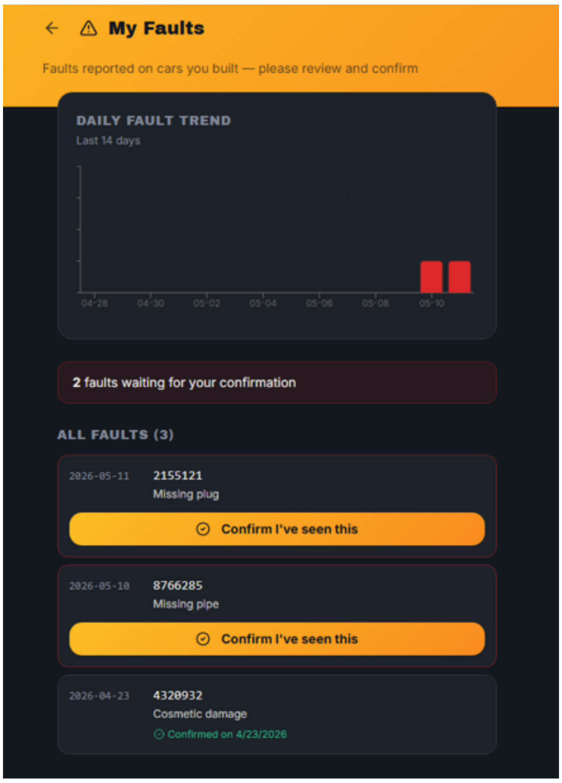

Figure 4.3: Error page in the LMS.

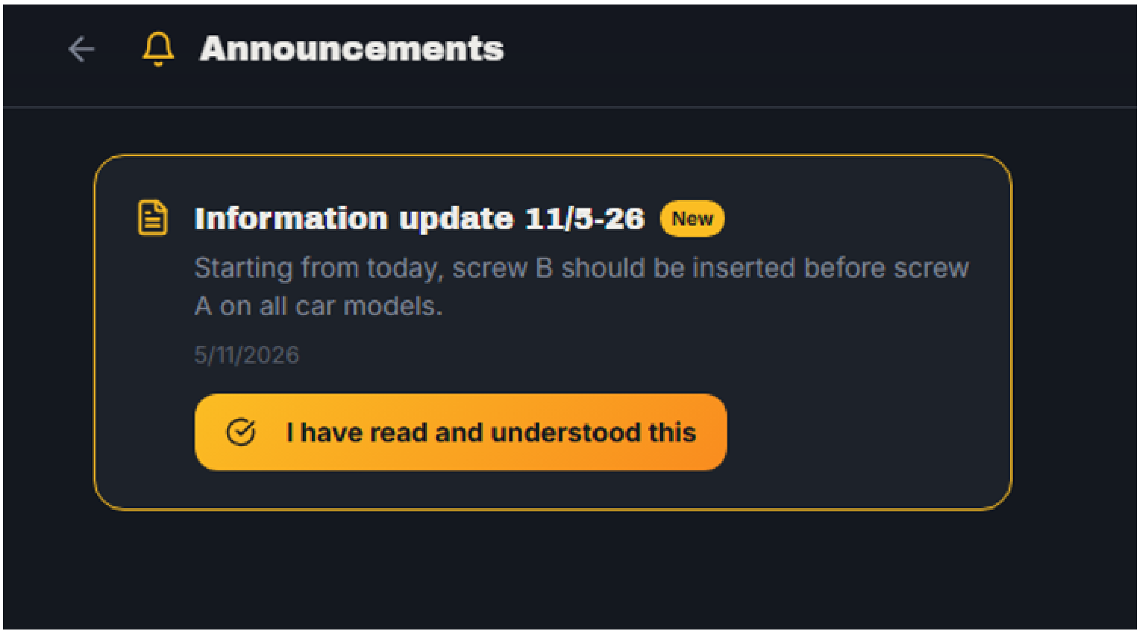

Figure 4.4: Information updates in the LMS.

The manager view is intended for team leaders and managers to coordinate learning activities, monitor learning competition status and follow-up on items such as sign-offs and error reports. It also provides a competence overview through quest progress and skill badges, allowing managers to identify who has completed specific packages and where additional support is needed. From this view, the manager can also configure the remedial training function, which automatically assigns refresher modules based on the operators' error statistics. For example, repeated errors (amount set by manager) leading to cosmetic damage within a defined timeline (also set by manager) can trigger automatic assignment of a clothing and jewelry policy module (see "A" in Figure 4.2 and Figure 4.5).

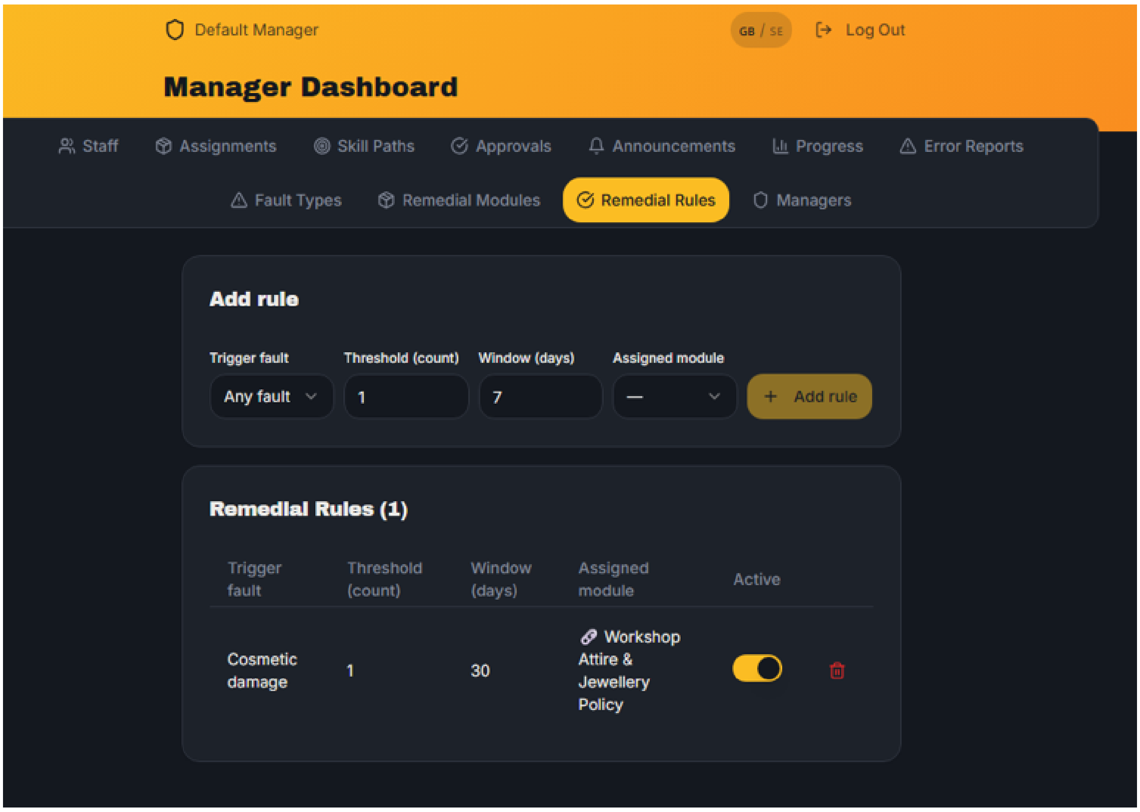

Figure 4.5: Manager dashboard in the LMS.

The developer view is intended for content owners (for example Plant Academy and Plant Launch) to create and maintain learning modules and packages. It is designed to be easily used and maintained, requiring limited specialized knowledge to create and update learning content. This is important for keeping learning creation closer to production and enabling fast changes when standards, stations or models change (see Figure 4.6).

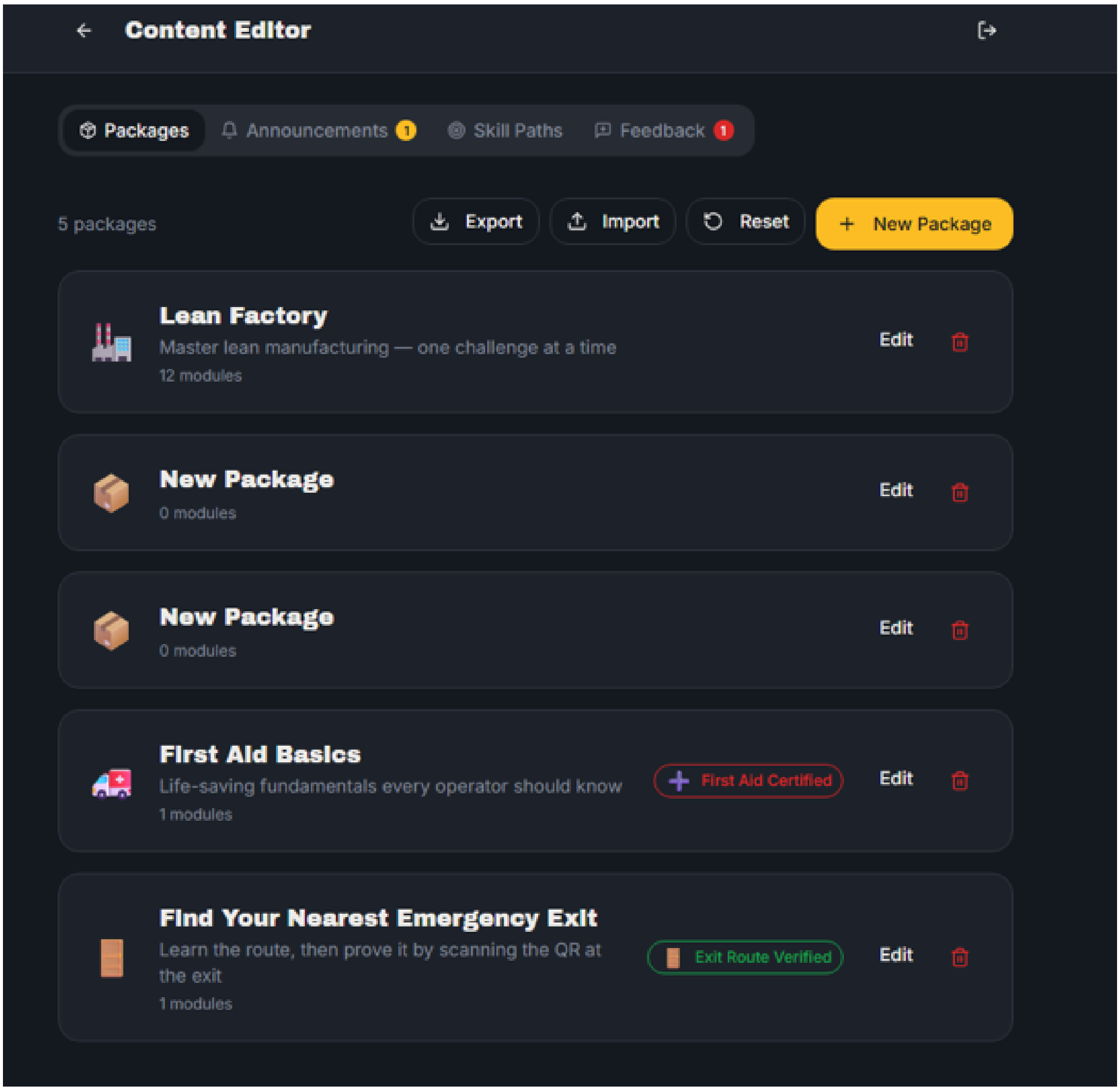

Figure 4.6: Developer view in the LMS.

In addition to the previously mentioned functions, the prototype concept identifies AR/VR capabilities as a potential future extension intended to support training in assembly work. However, within the scope and timeframe of this thesis, such AR/VR functionality was not implemented in the working prototype, due to the additional development time and resources required to build and validate such training scenarios. The functionality that was implemented in the prototype instead consists of QR-based contextual learning, where scanning QR-codes can trigger contextual content or be used for verification purposes (such as confirming that an operator has located the nearest emergency exit or providing short explanations of local production concepts) (see Figure 4.7). This QR-based contextual learning functionality exists as a demonstrable feature in the prototype, while AR/VR-based assembly training was not implemented in the working prototype and remains a proposed capability for further development beyond the prototype scope.

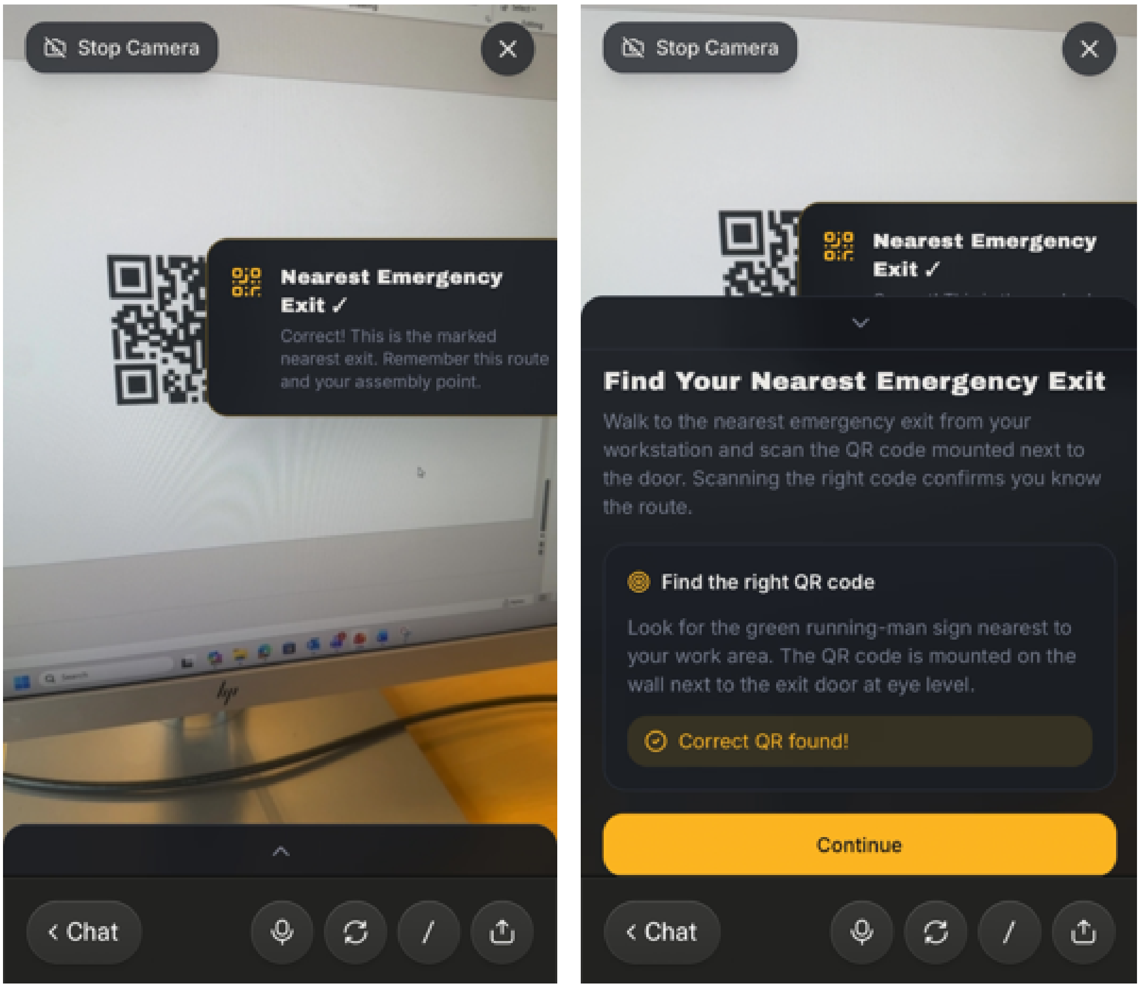

Figure 4.7: Demonstration of AR QR-code functionality.

Lastly, the LMS also has gamification capabilities integrated to improve user motivation. In an initial design state, there were mechanics for points, badges, and streaks, but it was quickly realized that these did not add much value and were unlikely to motivate operators, which was also confirmed by stakeholder feedback. Instead, gamification was used in the form of quests, implemented as self-assigned skill paths, where each quest (for example "New operator") provides a roadway of required modules and steps required for a certain outcome (see "B" in Figure 4.2 and Figure 4.8), with the intention of adding more role-based paths over time (e.g. becoming a team leader). Badges were reintroduced but linked to specific learning packages (e.g., a first-aid badge for completing first-aid training) (see "C" in Figure 4.2). During the stakeholder sessions this was perceived as more meaningful as they signal a concrete skill, and it also gives team leaders and managers a quick overview of who has completed which competence area.

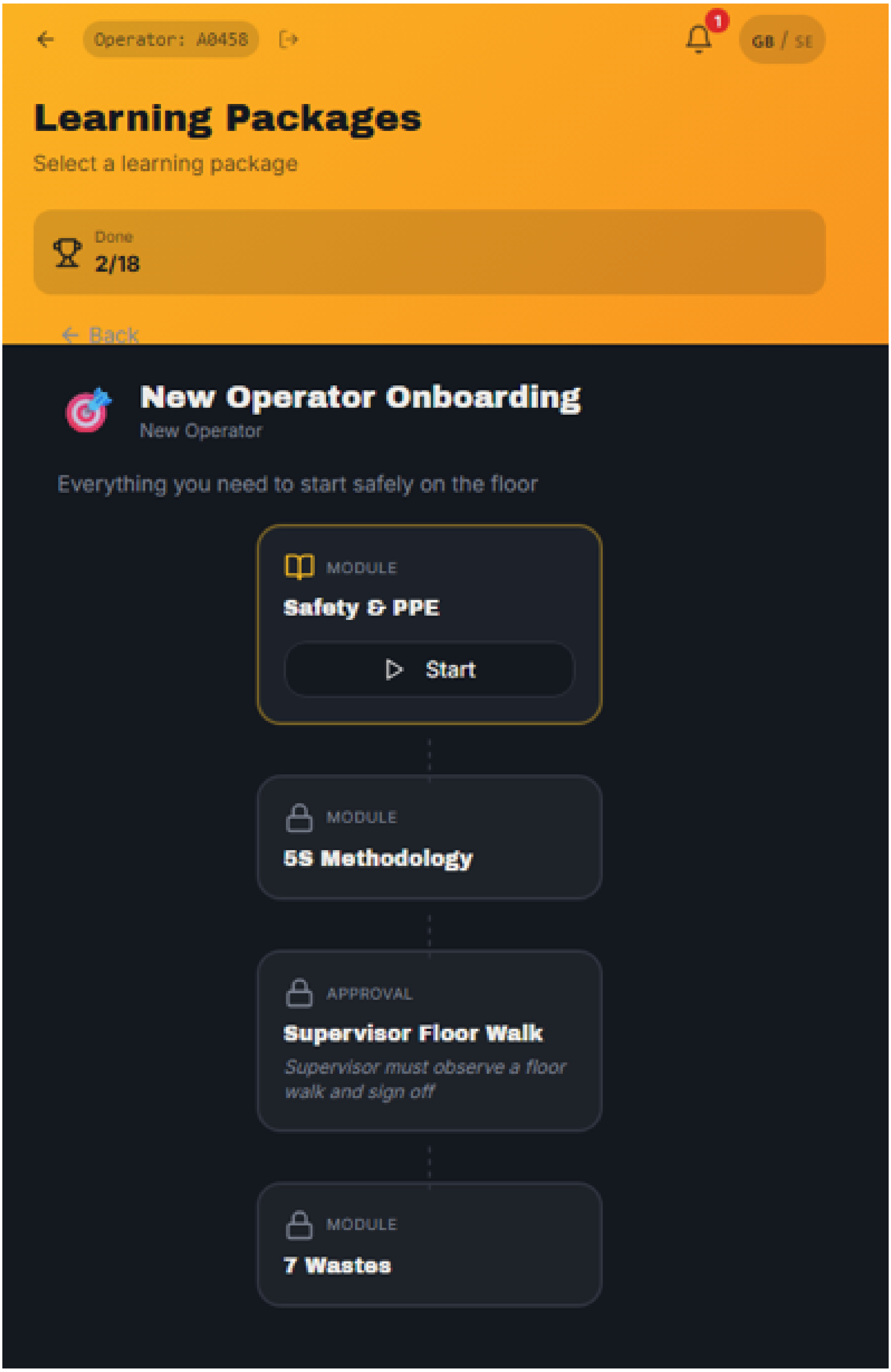

Figure 4.8: Skill paths in the LMS.

4.7.1 Feedback on the Prototype

To make the evaluation of the prototype more transparent, Table 4.4 summarizes the feedback gathered during prototype development and in the dedicated feedback sessions conducted at the end of the study. The purpose of this feedback was to assess the prototype's perceived usefulness, its fit with the shop-floor demands and which aspects were seen as most relevant or problematic by stakeholders. A limitation of this prototype evaluation is that it was qualitative instead of being based on structured usability testing, controlled user trials, or live production deployment. The feedback should be seen as stakeholder perceptions of fit, strengths, and limitations of the concepts rather than evidence of usability, learning effectiveness, or operational impact.

Feedback source	**Positive responses**	**Critical responses**	**Influence on final prototype**
3 operators (dedicated feedback session)	Found the microlearnings to be more easily digestible, competence badges were seen as a fun way to show off skills.	Points and streaks were not perceived as meaningful or motivating.	Points/streaks removed, quests and competence-linked badges retained.
1 team leader (dedicated feedback session)	Found the visibility of progression to be useful for mapping out skill gaps among operators.	No major critique of the overall concept was emphasized, but the need for practical follow-up on competence gaps and allocated time for learning activities was highlighted.	The manager view was strengthened to support additional ways of working with skill gaps, for example through remedial training linked to specific fault types. The issue of creating time for learning was retained as an implementation challenge and is discussed further in Chapter 5.
2 XR team representatives	XR-based training was considered relevant for contextual and scenario-based learning in the final assembly.	Full XR implementation not feasible within thesis scope due to development time and resource demands.	XR retained as future capability, QR-based contextual learning implemented instead.
2 Global Learning representatives	Liked the ability to get "in the flow" learning, i.e., getting relevant information at the right time.	Discussed potential implementation challenges, mainly how to integrate it within the rest of the learning systems within Volvo Cars.	No direct modification was made to the prototype, but the issue was retained as an implementation challenge and is discussed further in Chapter 5.
Informal feedback during prototype development	The system was perceived as creating better conditions for standardized learning across manufacturing sites.	In early versions, the LMS was treated as too separate from the other digital tools used in production, which was seen as a weakness. It was also noted that the concept still depends on time being created for learning in daily production.	Rotation cards, error reporting, and announcements were integrated into the LMS to gather more learning-related and operational activities within the same interface. However, the broader issue of integration with existing systems, as well as protected time for learning, was retained as an implementation challenge and is discussed further in Chapter 5.

Table 4.4: Summary of feedback and its influence on the final prototype.

5
Discussion

This chapter will discuss the results presented in the previous chapter as well as the choice of methods in this thesis.

5.1 Method Discussion

The thesis was done as a case study focusing on skills and learning within the final assembly at Volvo Cars. The case study approach was considered to be suitable as it supports deep understanding of how learning and competence development are shaped by production constraints such as takt time, product variety, time pressure and interaction between humans and technology. Since the study aims to understand current practices and explore how competence needs will evolve, it benefited from being grounded in a real operational context.

The research strategy was qualitative and included methods such as semi-structured interviews, observations, and document analysis. Qualitative methods were chosen due to the study being exploratory and as it explored a socio-technical system. The goal was not to measure effects quantitatively but to capture opinions, reasoning, challenges and constraints. The semi-structured interviews were useful for gaining different perspectives across roles and for getting insights that may not be visible through short observations. The observations provided contextual understanding of work conditions, and the document analysis provided another perspective by showing how training and standards are intended to work.

Together, these methods strengthened the study by enabling triangulation between what people said, what could be observed, and what was documented, which reduces the risk that conclusions rely on a single perspective. However, these methods also come with limitations. The interview data can be influenced by the participants' memory and what they consider appropriate to share, and during observations, behavior can be affected by the presence of the researcher. Additionally, the study focused on one plant, meaning that the findings could be affected by local culture and processes.

Another limitation was that proposed improvements were evaluated based on analysis and discussion rather than being implemented, tested, and evaluated based on quantifiable operational KPIs. Given the study's timeframe and the studied environment having low takt time and high operational sensitivity, there was not enough time to develop and validate a fully integrated solution in live production. Due to these limitations, caution should be taken when interpreting the results of the study. As the study is based on a single case company and plant, the identified competence needs, as well as the issues with the current learning and consequently the defined requirements, represent context-specific insights rather than universally applicable conclusions.

Furthermore, as the proposed prototype was not tested or deployed in live production, its effectiveness has not been empirically validated. Similarly, the proposed efficiency gains should be understood as hypothetical and exploratory, based on theoretical reasoning and qualitative stakeholder feedback, rather than empirically demonstrated. Further research is required to validate the proposed concept in practice and to evaluate KPI outcomes such as quality deviations and learning time under controlled conditions and during a prolonged timeframe.

5.2 Skills in the Future

This section will discuss how the anticipated technological changes will affect operator roles in final assembly at Volvo Cars and what future skills and knowledge requirements these will lead to. Building on the theoretical lens of the industrial revolutions, the interview findings indicate a continued move towards more digitally enhanced and interconnected work while the need for human adaptability due to high variation will remain, in line with Industry 4.0 and Industry 5.0. The competence profile for an operator is expected to become more hybrid, traditional assembly skills will still be relevant but must be combined with digital literacy, system understanding and problem-solving as automation and digital support becomes more present.

5.2.1 Summary of the Interviews

The interviews with plant management and manufacturing engineering point towards an agreement that final assembly will continue to develop more automation and digital support, although the interviewees have different opinions to how far this change will go within the coming 5–10 years. One reoccurring theme is that final assembly is difficult to fully automate because of product variety, fine motor skill requirements, and "everyday deviations" that humans can handle quickly. In a more automated future, manual labor is therefore still expected to remain in some form for complex and variable tasks.

The interviews also highlight several technological shifts that will likely become more relevant in final assembly: automation for heavy, repetitive and standardized tasks, increased quality checks through AI/vision-systems, more digital monitoring, systems generating information and producing alarms and use of AMR/AGV solutions in logistics. These developments will change how the work is controlled and coordinated; attention and decision-making will depend on interpreting system signals, managing deviations, and collaborating with automated systems except for just performing manual tasks.

5.2.2 Interpreting the Interview Findings through Industrial Evolution

The picture painted by the interviews aligns with the description of Industry 4.0 as a shift towards more connected production systems where operators interact with digital interfaces, monitor processes, interpret data, and respond to deviations. During the industrial evolution described in the theoretical framework, earlier revolutions emphasized standardization and specialization and the third industrial revolution introduced automation and contributed to a polarized skill structure between “knowledge workers” and lower-skilled operational roles. Industry 4.0 blurs this divide by introducing digital technologies into shop-floor work and expanding competence requirements toward digital literacy, system understanding, and problem-solving.

The findings from the interviews seem to reflect this shift. The expected increase of AI/Vision-based inspection and digital monitoring will lead to quality and performance work becoming more data enhanced and system driven meaning that operators and support staff will be required to understand system outputs, evaluate their reliability and what actions to take. The expected maturation of AGV/AMR logistics and increased automation also suggests an environment where human work is shaped by interactions with automated material flow and how machines behave.

The interview findings also align with the theory of Industry 5.0 that emphasizes human-centric production and complementary strengths between humans and technology. The interviewees stated several times that the final assembly remains hard to fully automate because humans are better at handling variety, fine adjustments, and contextual judgements. This supports a future where technology will be used to augment human performance like reducing ergonomic strain, improving consistency in inspection, and enabling better situational awareness, rather than replacing human labor entirely in final assembly. Future competence requirements should be designed around collaboration with technology while also preserving and strengthening distinct human abilities.

5.2.3 Role Evolution

Because final assembly involves variation, fine motor work and frequent small deviations, manual assembly skills will remain central. Operators will continue to need procedural dexterity, i.e., the ability to handle flexible materials and tacit “quality-by-feel" skills that allow for quick corrections of fitment or alignment issues. This means that future work is not a linear move away from manual competence as technology increases. Instead, it indicates a rebalancing of competence. As automation is introduced where it clearly adds value, the manual tasks that remain tend to be those that require human adaptability and fine judgement. Manual competence will remain the foundation for stable performance because of the human ability to handle variability and deviations in a complex environment such as final assembly.

Along with manual competence, the anticipated growth of digital monitoring and AI/vision-based inspection suggest that operators increasingly will need to understand and act on information presented by digital systems. The interviewees described a future with background monitoring that generates status reports, alarms and performance information meaning that attention will shift toward interpreting and responding to system signals. This implies that operators will need a bigger baseline of digital literacy (i.e., navigating interfaces and understanding alerts and system states) and practical system understanding (i.e., knowing how automated subsystems work, recognizing typical failure modes and responding correctly without safety or quality risks). A related competence need is critical judgement around AI-enabled support. One interviewee raised the risk that as AI becomes more common, employees will need foundational understanding to evaluate AI outputs rather than relying on answers they do not understand. This becomes more relevant as AI/vision-systems are increasingly used for quality control and deviations but also for other tasks where AI tools are used.

During the interviews, problem solving and logical thinking were described as central to assembly work regardless of what tools are used. As automation and digital monitoring increase, the nature of problem solving will change. Operators will have to diagnose issues that may be mechanical, digital or socio-technical (i.e., issues emerging from interactions between tools, systems, and humans). This increases the importance of structured troubleshooting, situational awareness, and the ability to decide when to intervene or escalate, under takt-time constraints. The interviewees also emphasized the continued importance of people-related capabilities "EQ" and working with others, meaning that these aspects will continue to be relevant or even more important as more automation and machines are brought into the production environment and cannot be replaced by AI. These findings align with the proposed human-centric production model in Industry 5.0 where collaboration, adaptability and contextual understanding become complementary to technology.

5.2.4 Risk of New Polarization

The findings from the interviews suggest that the largest role transformation may occur in maintenance or technical support roles. The interviewees described a need for "good troubleshooters" and pointed out that maintenance will become more technically challenging and engineering oriented as automation and connected systems increase. One of the interviewees also highlighted a competence challenge within manufacturing engineering, that mechanically strong profiles lack digital competence while software-oriented profiles lack mechanical understanding and that there is a need for combined perspectives in troubleshooting and development of tomorrow's production systems. Additionally, the interviewees meant that there is a growing need for roles close to the line who can reprogram or adjust robots as the number of robots increases, to reduce reliance on external suppliers.

Interpreted through the industrial revolution lens, this could lead to a potential emergence of skill polarization if the competence development is not handled properly. Historically, the third industrial revolution contributed to a division between knowledge workers and shop-floor workers. Industry 4.0 and Industry 5.0 could theoretically reduce this divide by including technological knowledge into operational work and emphasizing socio-technical competence. However, the interview findings suggest that digital competence may concentrate in specific roles unless a broader baseline competence is established across the shop floor. For Volvo Cars, this means that "future skills" should not only be defined for specialist roles but also include a general baseline competence for operators so they know how to effectively interact with digital systems, interpret feedback, and collaborate with automated processes.

5.2.5 Uncertainty and Pre-skilling

During the interviews, a notable finding was the lack of consensus regarding how far automation and digitalization will progress in final assembly within the 5–10 years. Some interviewees described a development primarily as incremental add-ons in selected areas, such as increased automation for ergonomics. Others believed that there would be a more substantial structural shift with fewer traditional operator roles and stronger emphasis on troubleshooting and interaction with automated solutions. The uncertainty is not only uncertain in timing but also in direction.

This uncertainty has implications for Volvo Cars' competence strategy. If the future state of work cannot be specified, competence development efforts that are too narrowly defined for specific scenarios might become misaligned. The most robust competence investments are instead those that strengthen employees' ability to adapt to multiple futures. From this perspective, adaptability, learning speed, and capability to cope with change are also important forms of competence.

This aligns with the theory of pre-skilling as a proactive approach to competence development. Rather than focusing only on specific skills tied to known technologies, pre-skilling emphasizes strengthening capabilities that remain valuable under uncertainty. This includes human capabilities such as curiosity, resilience, problem-solving, and the ability to learn and unlearn as work content evolves. It can also include foundational technical capabilities such as digital literacy or basic programming or automation logic even if the "right" future systems or programming languages are not yet known. The value of this type of competence is its transferability. Understanding fundamental concepts such as logic, troubleshooting, and interpreting system outputs makes it easier to adopt new tools and roles as demand changes. In a context where technology and roles may change unpredictably, these capabilities will increase the likelihood of employees being able to successfully transition as there are new demands.

5.3 Interpreting Current Learning Challenges Through Learning Theory

The interview findings reveal a discrepancy between the learning environment described by new operators and the theoretical perspectives on learning presented in Chapter 3. This section explains how psychological safety, cognitive load, multimedia learning principles, and training design influence operators' ability to acquire skills in a complex and time-pressured production environment.

5.3.1 Cognitive load and Information Processing

The operators' experience of information overload during Step 1 at Plant Academy closely reflects the challenges described in Cognitive Load Theory (CLT). According to CLT, working memory has limited capacity and excessive or poorly structured information increases extraneous cognitive load which can make learning inefficient but also impossible (Sweller, 2010).

The operator's experience was that the introduction "contained too much information at the same time" and that it was impossible to remember what was taught. This shows an increase in extraneous cognitive load described in CLT, a load which is caused by instructional methods that do not directly support learning such as lecture heavy delivery, repetitive content, and lack of focus of essential information.

In addition to high extraneous load, the information also demonstrated poor management of intrinsic cognitive load, which is related to the complexity of the material. CLT emphasizes the importance of framing, sequencing, and breaking complex information into manageable steps. The operators, however, did not experience a gradual build-up of difficulty, segmentation or anchoring information as new concepts were introduced. This unstructured presentation forces the learners to process multiple interacting elements at the same time, which quickly fills up working memory capacity.

Another important aspect of CLT missing in the training is germane cognitive load i.e., the effort needed to build and integrating newly learned information into existing mental models to support long time learning. To optimize germane load, learners should be able to actively engage with the learning content, relate new information to prior knowledge and practice applying it in relevant contexts. According to the interviewees, this was absent from the current onboarding.

This is also supported by findings from Dunlosky et al. (2013) who rank learning techniques based on their effectiveness. The techniques with the highest utility, i.e., practice testing and distributed practice are known to strengthen memory, reveal knowledge gaps, and promote sustained learning, conditions that also support germane load. None of these techniques were present in the Plant Academy introduction. Instead, the introduction relied on low-utility techniques such as passive listening, repetition, and dense theoretical explanations, which produce weak long-term retention and increase the risk of cognitive overload.

CLT and the research on effective learning techniques show that the current onboarding design increases extraneous load but also fail to stimulate germane load and support strategies that are known to enhance learning. This helps explain why operators reported difficulty remembering the material and why the introduction had a limited impact on their preparedness when entering the production environment.

5.3.2 Psychological Safety

The interviews indicate that the operators experience high tempo pressure and early performance expectations in final assembly, which many describe as stressful. Such conditions are similar to the description of contexts according to Edmondson where high stakes and time pressure can suppress learning behavior unless there are deliberate measures to protect them (Edmondson, 1999).

The interviews do not indicate a lack of interpersonal safety; most operators describe supportive mentors and colleagues, and several mention that it is okay to "pull andon" when needed. Instead, the barrier to learning appears to be situational rather than social. Operators frequently mentioned takt time, fast pace, and the psychological pressure of "not wanting to fall behind," which limited opportunities to ask questions or reflect during the cycle. Even if there is a socially supportive climate, the continuous flow of production restricts the time available for these behaviors to occur. This finding is consistent with Edmondson's argument that learning behaviors require time and temporary inefficiency which make them difficult to use in time-critical environments such as automotive assembly.

Another aspect that emerged in the interviews is that confidence with andon and production information systems appears to be uneven. Some operators reported that they frequently use andon to call for help while others felt that they still did not fully understand andon procedures or the overhead screens after onboarding. This difference also suggests that psychological safety is important but not enough for effective help-seeking. Clarity of systems and procedures must also be ensured, so operators know when and how to escalate issues under takt pressure.

Overall, the interviews findings show that there exists a learning environment where interpersonal safety is generally present, but where situational constraints tied to takt time, tempo and system literacy limit the ability to act out learning behaviors. This helps explain why some operators expressed that it took weeks or months to feel confident, despite receiving support from their mentors.

5.3.3 On-the-job training versus Off-the-job training

The onboarding model at Volvo Cars includes both offline skill training and online skill training, but interviews reveal that the offline component is rarely implemented.

Several operators explained that they did not receive any structured offline training before entering the line, despite the global instructions stating that offline skill development should be used. Instead, most operators begin practicing directly in the real production environment from their first day on the line.

This deviation aligns with what training theory highlights typical strengths and weaknesses of on-the-job training. The main benefit is realism; operators immediately encounter the real work, tools, and time constraints which several interviewees appreciated because it allowed them to “get into the work” quickly. However, on-the-job training also introduces challenges related to production pressure, social evaluation, and operational risk related to quality and safety (Martin et al., 2013). These challenges were reflected in the interviews. The operators described a fast pace, limited time for questions and a desire not to fall behind, which reduces opportunities for reflection and experimentation when learning. Additionally, some operators pointed out that certain tasks could be risky or overwhelming to learn under full takt pressure, especially when they were involved using high forces or awkward motions that were not practiced beforehand.

In theory, off-the-job training offers protected learning time, standardization, and reduced safety and quality risk through structured simulations (Martin et al., 2013). The Simulated Work Environment (SWE) at Volvo Cars is intended to provide such a buffer. However, operators reported that SWE lacked pace, sequencing complexity, and cognitive demands of real assembly work. According to Wickens et al. (2013), simulations can only support transfer efficiently when they replicate the critical cognitive and procedural elements of the task, regardless of physical appearance. Since SWE did not reflect these essential characteristics, capabilities such as handling task pressure, coordinating multiple sequential steps, and handling variability were not practiced sufficiently.

The gap between the indented onboarding process and the training operators receive means that the early stage of learning occurs almost entirely through on-the-job training. In combination with the low cognitive realism of SWE, this results in new operators having to encounter full task complexity, takt time and procedural variation before having the chance to practice these elements in a controlled environment. Instead of building understanding and automatizing task elements offline, operators develop these skills directly in production, which contributes to longer ramp-up times and greater dependence on the mentor’s instruction and pacing.

5.4 Alignment of Proposed Prototype with Theory

This section discusses how the technologies and learning concepts chosen for the prototype align with the theoretical framework presented in Chapter 3. The intention is to explain why specific choices of concepts and technologies were considered suitable and what they are expected to support.

5.4.1 Cognitive load and the Need for Structured, Segmented Learning

One key finding from the interviews was the experience of information overload during step 1 at Plant Academy where operators described that “too much information” was delivered at once and that it was not realistic to remember what was taught. This aligns with CLT, which emphasizes that working memory is limited and that learning becomes inefficient when cognitive demands exceed capacity (Sweller, 2010). The onboarding design described by the operators suggests a high extraneous cognitive load which is driven by lecture-heavy delivery and insufficient structuring of content into manageable elements. Also, intrinsic load was not managed through sequencing and gradual build-up, instead multiple interacting concepts such as culture, rules and lean principles, were introduced without immediate opportunity for application, increasing the likelihood of overload.

An LMS-based microlearning structure addresses this problem by enabling segmentation, sequencing, and paced delivery. Microlearning is defined as short, focused learning segments for quickly developing specific knowledge or skills with relevance for reducing cognitive load through chunking and prioritizing important information (Ingram Nissen et al., 2023; Sweller, 2010). From a CLT perspective, microlearning supports the reduction of extraneous load by removing non-essential details and presenting content in smaller units. Additionally, microlearning supports management of intrinsic load when modules are designed as a progression from basic terms and concepts toward more complex interactions.

CTML provides concrete principles for designing effective microlearning modules (Mayer, 2017). CTML’s segmenting principles say that learners benefit when complex processes are broken into user-paced segments, and its pre-training principle suggests that learning improves when key terms are introduced prior to more complex lessons. This means that “shop-floor lingo” and foundational concepts should be introduced as short pre-training modules before the operators enter high-tempo environments. CTML’s coherence and signaling principle implies that onboarding content should exclude “interesting but unnecessary” information and highlight essential information, which addresses the operator’s perception that parts of the introductory content was repetitive or “fluffy” and weakly connected to the role.

However, the literature notes a limitation; microlearning can cause learners to lose sight of the “big picture” and struggle to connect dependencies between tasks and concepts (Ingram Nissen et al., 2023). Microlearning should therefore not be implemented as standalone modules but within a broader learning path, hence the LMS based approach, so that segmentation reduces overload without fragmenting understanding.

5.4.2 From Low- to High-utility Learning

Beyond the structure of content, there is also a lack of methods that produce retention and sustainable learning. The operators reported that content was difficult to remember and the educators described that there was no structured or standardized method for verifying whether the participants had acquired the intended knowledge during the introduction and that approval was mostly based on attendance. The theoretical framework instead emphasizes practice testing and distributed practice as the highest-utility learning techniques for retention and transfer and that passive listening and repetition as low-utility learning (Dunlosky et al., 2013).

An LMS enables integration of practice and spacing into the onboarding. By delivering short modules with quizzes, scenario questions or micro-assessments, practice testing can be a routine part of the introduction. Microlearning delivered over time also supports distributed practice by enabling operators to revisit key concepts during several days or weeks instead of concentrating them into a single intensive day, addressing the overload described by the operators and supporting long-term learning. From a CLT perspective, this would also increase germane cognitive load by creating opportunities for active processing (Sweller, 2010), connecting new information to prior knowledge, detecting knowledge gaps, and strengthening knowledge.

This is also relevant to the verification in step 5. According to the interview findings, signatures in the Operator License Matrix often reflect the ability to replicate assembly steps rather than demonstrating deeper understanding of standardized work documents, support systems, and escalation routines such as using andon. An LMS could strengthen the verification by enforcing sign-off not only for observed station performance but also from assessments on system literacy (e.g., andon usage, interpreting screens, recognizing quality-critical steps) and by documenting completion of relevant practice modules over time. This would lead to the verification being more transparent and standardized compared to the largely qualitative judgement that exists today, thereby ensuring better readiness in terms of quality, safety, and delivery.

5.4.3 XR inside the LMS

A common deviation between the standardized onboarding model and actual practice is that the offline training elements in step 3-4 are rarely implemented due to shortages of time and personnel, resulting in early learning taking place directly in live production under takt time. This is problematic both from a training-design and psychological safety perspective. While on-the-job training provides authenticity, it is constrained by production pressure and hidden costs, errors, and quality/safety risks while off-the-job training offers greater control, standardization and reduced operational risk (Martin et al., 2013). Additionally, although interpersonal support is generally present, the interviews indicate a situational barrier where takt time and the pressure of “not wanting to fall behind” restricts opportunities for questions and reflection, making learning behaviors harder in practice (Edmondson, 1999). Plant Academy partially compensates with SWE, but the operators report limited realism, complexity, and urgency, which contributes to weak learning, aligning with the theoretic framework that simulations must reproduce key cognitive and procedural elements rather than relying on visual realism (Wickens et al., 2013).

Based on this, integrating XR capabilities (AR and VR) can be understood as future extensions of the LMS concept that may enable scalable off-the-job practice opportunities that are currently absent in steps 3-4. In Section 2.5, VR is categorized as an immersive simulation method supporting risk-free and repeatable practice, while AR is categorized as augmented guidance. The key question is therefore not which XR technology is better than the other, but how VR and AR can be combined as complementary offline methods to support learning progression.

VR is described as a computer-generated environment that enables interaction and manipulation with a sense of presence and immersion and is highlighted in literature as effective for training when real-world practice is expensive or dangerous (Wickens et al., 2013). In this case, VR's strongest justification is that it can provide controlled repetition and structured progression for those elements that are difficult to learn under takt pressure and were insufficiently trained in SWE (e.g., sequencing complexity and tempo-related cognitive demands). From a CLT perspective, these VR scenarios should break down complex tasks and increase difficulty gradually while minimizing extraneous load to support learning (Sweller, 2010). From a CTML perspective, they should be segmented and designed with coherence and signaling to essential information is highlighted, and nonessential details excluded (Mayer, 2017). However, it is noted that VR does have several constraints such as high initial costs and risk of lag, disorientation and cybersickness (Wickens et al., 2013), meaning that VR should be targeted to learning objectives where the value of controlled repetition is high enough to justify these constraints.

AR is defined as overlaying virtual information onto the physical environment in real-time, enabling interaction with both virtual and real elements and reducing the need to shift attention between instructional media and physical tasks (Buchner et al., 2021; Cheymol et al., 2025). This is particularly relevant for the intended offline training in Steps 3–4, where operators are meant to practice tasks on physical fixtures or car bodies outside the line, but where training is reported to be rarely implemented due to time and personnel constraints. AR can be seen as a tool for increasing the feasibility of offline practice by integrating guidance directly in the operator's field of view, reducing the dependence on mentor availability and enabling more standardized repetition of tasks. AR is further motivated by the interview finding that Plant Academy's practical training does not sufficiently represent physical demands such as force, difficult angles, and handling tight or stiff components, demands that can also be challenging to practice under takt-time pressure. Compared to VR, which places the learner in a fully virtual environment, AR preserves physical interaction with real objects while adding situated guidance which is more suitable for learning assemblies where procedural dexterity is of importance.

The potential value of XR as a future extension increases when AR and VR are combined because they address different training needs that surfaced in the thesis. A way to decide between them is by determining what makes the task hard for a new operator. If the difficulty is primarily cognitive/procedural i.e., understanding the correct sequence, coordinating multiple steps, and coping with the takt-time then VR is the better offline choice because it enables repeatable scenario rehearsal of these cognitive and procedural elements in a controlled environment. VR would also be suitable when practicing in the live environment is too risky or costly due to the potential consequences of errors during training (e.g., quality/safety risks and other operational impacts associated with mistakes made in real production. If the difficulty is primarily procedural dexterity, for example steps where the challenge is applying force, working in difficult angles or handling stiff components, then AR is the better offline choice because it preserves interaction with real objects while providing situated guidance that reduces mental translation between instruction and action.

During the interviews, it was identified that AR/VR initiatives have previously been explored in smaller concepts, not necessarily for an education purpose, but for trying new assemblies or doing ergonomics studies, but that several efforts were discontinued due to high scenario development costs and corresponding business cases did not justify continued investment. This implies that the limiting factor is not whether AR/VR is technically possible but if it can be implemented in a way that it is economically sustainable and scalable over time. From a technical perspective, there already exists several prerequisites within the organization such as digital product models, AR/VR competence, and hardware, but these are distributed across different functions and are not coordinated. To deploy AR/VR across plants, these capabilities would need to be consolidated through a joint effort to reduce the marginal cost per scenario. More concretely, this would mean developing a set of standard scenario templates for the most reoccurring training needs and building a library of XR building blocks that can be maintained centrally. New AR/VR scenes could then be built by selecting a template, choosing the correct product model and the intended offline setup, and populating it with relevant training modules (like tasks, steps, checks), instead of doing full development work for each scenario. To make this practical and usable in the plants, there needs to be a user interface where scenarios are assembled through configuration instead of programming, “drag-and-drop", which allows users with limited technical background to create new scenes.

5.4.4 Gamification as Support Mechanism

A transition toward an LMS-based onboarding process would mean that operators themselves will need to take a higher accountability for their own progression and learning. This increases the importance of designing the LMS in a way that supports sustained participation and makes progress visible. One approach is to use gamification to strengthen engagement and provide clearer signals of progression. Gamification refers to the use of game elements (e.g., points, levels, badges, and challenges) in non-game contexts in order to increase engagement and goal-directed behavior (Christopoulos & Mystakidis, 2023). To avoid “pointification,” where rewards mainly reinforce activity (clicks, login, completion) rather than meaningful learning, game elements such as levels, badges and progression should be tied to demonstrated competence, just not participation. Progression should depend on evidence of learning such as assessments, scenario completion, or verified understanding of key operational concepts. Badges and milestones can signal capability and increase confidence if they represent meaningful mastery of the content.

5.4.5 Technologies not Chosen

Smart gloves are primarily "intelligent feedback and monitoring" technology which can be helpful for objective coaching and ergonomic feedback (Sharma et al., 2026). However, the literature review indicates that smart gloves are still an emerging technology and are still in the prototype phase, meaning that it is uncertain if they will be robust enough to deploy large-scale in 5–10 years. Also, given that the most critical onboarding issues in this case concern content overload, transfer, and standardized onboarding rather than measurement, smart gloves were not prioritized but may be relevant in the future as an add-on to strengthen verification in step 5.

Cobots mainly influence operator competence indirectly by changing tasks and roles and increasing the need for human-robot collaboration rather than functioning as training tools. There are some examples of cobots being used for training purposes (Semeraro et al., 2024) but there is not sufficient evidence to propose the technology as an upskilling tool. Cobots where therefore excluded from onboarding proposal, but their adoption will likely increase importance for digital literacy and system understanding in a future state.

AI-driven personalization and skill-gap analysis can support adaptive learning pathways and targeted feedback (Espinoza, 2025) but the adoption of AI into the LMS requires reliable data and organizational readiness. The initial priority is to establish a coherent learning path and assessment through the LMS before adding advanced functionality. AI can be a potential future add-on to the system as the foundational learning content, assessments and data structures are in place.

Serious games can enable constructivist learning through complex simulations and interactive practice (Brauner & Ziefle, 2022), but they require substantial development effort to balance realism, usability, and learning objectives. In the initial proposal, the design therefore relies on lighter gamification within the LMS (progression and feedback mechanisms) combined with AR/VR scenarios rather than developing full standalone serious games.

Digital twins provide realistic virtual representations that can support advanced scenarios and training but developing a highly realistic and continuously updated digital twin requires significant integration with engineering and shop-floor data streams. Given the thesis's focus on onboarding improvement within the coming 5–10 years, digital twin technology does not seem feasible but can be of interest in the future.

5.4.6 Implementation Challenges

While the proposed LMS concept might be suitable based on the empirical findings and the theory, implementing the system still comes with challenges. The concept addresses several identified learning challenges, but successful implementation would require organizational conditions beyond the prototype itself. Firstly, ownership of learning content would need to be clearly defined. Even if the prototype is designed to be easy for content owners such as Plant Academy and Plant Launch to use, implementation would still require clear responsibility for creating, updating, approving, and retiring learning content. This is especially important for station- and model specific content, which are linked to OIS/WES, since the interview findings showed that standards and stations setups change might change during training periods, especially during new model introductions. A possible mitigation could be to manage OIS/WES digitally and link them directly to the LMS so that updates can flow more easily into the related learning modules. Additionally, the feedback functionality in the LMS could support continuous improvement by helping content owners identify unclear, outdated, or frequently revisited modules that may need rework.

Secondly, implementation would also require integration with existing systems. Stakeholder feedback suggested that integration with the broader learning ecosystem within Volvo Cars may be challenging, particularly since many of these kinds of services are purchased from external suppliers. The challenge would be to find a solution which can support the specific needs of the final assembly while also fitting the needs for other learning activities within the organization as the goal is to reduce the number of parallel systems. Without sufficient integration, there is a risk of duplicated administration, fragmented information flows, and unnecessary system costs. Related to this, data access and privacy would also need to be addressed as the proposed concept includes individual learning progress, manager dashboards, and error history. Clear principles would therefore be needed regarding what data is stored, who can access it, and how learning related data is used in ways that support development rather than being perceived as surveillance. This could influence acceptance among operators and worker representatives, including labor unions.

A further implementation challenge concerns how time for learning would be created in production. The empirical findings showed that training is already constrained by time pressure, staffing shortages, and takt time constraints. During the feedback sessions with stakeholders, it was also highlighted that continuous learning activities are deprioritized as these are not institutionalized. In daily work. Even with a microlearning-based solution designed to fit into short time windows, some form of protected learning time would still be needed for the system to be used as intended. In practice, this would require management support and clear routines for when learning activities are expected to take place, for example during structured onboarding periods and during planned windows during reduced-load situations.

5.5 Evaluation of Proposal

The purpose of this section is to address RQ3 by discussing the potential operational implications of improved skills and the proposed learning concept in the final assembly. Since the proposed solution to learning within the final assembly was developed and validated through a prototype and not a complete and fully working system, a comprehensive evaluation based on numerical data is not possible. The evaluation is therefore qualitative and based on insights from interviews, observations and stakeholder feedback and structured into personnel and workplace effects, flexibility and technology readiness, time implications, and quality implications.

5.5.1 Personnel and Workplace Effects

The interview findings suggest that new operators often experience the early phase in production as stressful due to tempo and limited time for questions, even though the mentors are seen as supportive. Based on these findings, enabling offline training through AR and VR before being introduced to the real line may help the operator practice the work sequence repeatedly and try different assemblies relevant to their line in a protected environment. This is expected to contribute to a baseline understanding and confidence, making the learning slope less steep, which could reduce uncertainty and provide a less stressful onboarding.

Additionally, increased competence could also improve workforce stability. Improving competence development and making progress more visible could create a workplace where employees experience clearer development and higher confidence. Based on the interview findings and discussion with stakeholders, some operators argued that current development pathways are unclear, for example, how to progress to a team leader role. As roles develop toward more interaction with technology and problem-solving, the work content may become more varied compared to today's repetitive manual tasks. This could increase perceived meaningfulness and development opportunities, leading to increased workplace attractiveness. This could both attract new talent but also help retain experienced and talented employees within the company.

5.5.2 Flexibility and Ability to Advance Technologically

A more skilled workforce may improve efficiency through improved task execution, more robust variation handling, and better interaction with digitalized production environments. Operators with good system understanding and digital literacy are expected to interpret production information more reliably, which reduces uncertainty and the risk of incorrect actions during disturbances. Stronger problem-solving capabilities may also support earlier and more accurate diagnosis and escalation of deviations, which could help reduce longer disruptions and repeated mistakes. Increased competence may also make it easier to adhere to standardized work by reducing the need to rely on shortcuts or improvisations.

Higher competence may also enable higher operational flexibility and organizational readiness for technology adoption. Final assembly is characterized by frequent changes and high product variety, which increases the value of being able to redeploy and reorganize operators for new stations or work duties and implement new standards or ways of working. Having a more skilled workforce is therefore expected to improve flexibility by reducing dependence of a few experienced individuals, enabling cross-training, and improving resilience during major changes. Increased competence, especially in interaction with digital systems and understanding system outputs may also provide a better foundation for major technological implementations and reduces the risk that technology investments are underutilized due to competence gaps.

By structuring learning in one place through the LMS, it may also become easier to identify and follow up on competence gaps. Compared to the current fragmented learning activities, a centralized system provides could provide clearer visibility on who has completed which topics that usually generate mistakes and where refresher modules are needed. This could support targeted training interventions, for example assigning specific microlearning's to affected operators instead of needing to have broad briefings for everyone. Using a centralized solution could also allow for faster response when new standards or work content are introduced and makes competence readiness more transparent, which could reduce the risk that gaps are hidden until they show up as disruptions in live production.

5.5.3 Time Implications

In the short term, time-based performance will likely be neutral or negatively impacted because structured learning will require time allocation, both for offline skill training during the onboarding but also regular slots where time is allocated for continuous learning. Over time, however, a more skilled workforce may reduce operational time losses due to lack of knowledge and uncertainty. Operators with for example good system understanding, digital literacy and problem-solving capabilities are expected to better interpret production information and diagnosing and escalating deviations faster which could reduce longer disruptions and repeated mistakes.

Implementing an LMS system with the previously mentioned functionality and institutionalizing learning in production will require time, time that is expected to be regained if the system becomes more stable and less dependent on reactive learning when issues arise.

5.5.4 Quality Implications

Quality improvements are one of the most plausible efficiency gains of the proposal. In the current state, operators are trained via mentor demonstration and OIS/WES are not always used as the backbone of training. This can result in a situation where operators may learn the task sequence but not learn following the standard or understanding why specific steps matter, which may increase the risk of deviations and inconsistent handling in abnormal situations. In the current state, introduction is also heavily educator dependent as this part of training is heavily lecture based, which may make it harder to know if all necessary material is covered or not.

In the proposal, the onboarding process is standardized, making sure that all new operators are subject to the same information and makes standardized work instructions easier to access. Offline skill training could also be linked to standards, and AR/VR solutions may reduce dependence on individual mentors, ensuring that all operators learn the correct sequence and get the time to understand why certain steps matter. Dedicated offline training could therefore make sure that the operator has some pre-understanding of the work to come on the line, which can mitigate the risk of serious quality errors when they start training online.

In the current state analysis, it has also been identified that verification processes linked to continuous learning activities such as error reporting are just sign-offs but does not verify demonstrated understanding. Operators sign without reviewing the content, and the process lacks follow-up that would ensure learning or behavioral change. Similarly, during the onboarding process approval is based on participation and engagement instead of standardized assessments meaning that operators can complete the introduction without being sure that they know the key concepts needed in production. In the proposed concept, verification is embedded within the learning modules and must be completed before progressing. This is expected to increase the likelihood that misunderstandings are detected early, and that competence gaps do not surface as deviations in live production. Additionally, the use of practice testing (e.g., short quizzes or self-assessments) is theoretically expected to support retention and makes knowledge gaps visible for both the operator and the organization.

6
Conclusion

This thesis aims to investigate future skill requirements within the final assembly at Volvo Cars due to technological and organizational developments, and how these competencies can be effectively developed to support operational performance. The study combines a theoretical understanding of Industry 4.0 and 5.0, emerging technologies, and learning with empirical insights from interviews and observations to provide a coherent picture of emerging skill demands and how to enable effective and efficient learning.

The findings show that final assembly will most likely not become fully automated within the next 5–10 years but rather move towards an increasingly complex collaboration between human and technology. Manual assembly skills will remain crucial due to manual dexterity and product variation with the need for contextual judgement, but they will need to be complemented with digital literacy, system understanding, and problem-solving capabilities, making the operator of the future more of a hybrid role where operational expertise is integrated with the ability to interpret, interact with, and act upon digital systems. However, in line with Industry 5.0, social capabilities and adaptability will remain critical, suggesting that human competences are not replaced, but shifted into new circumstances.

Further, the study finds a misalignment between the intended and current state of learning. Onboarding practices and continuous learning are characterized by high information load, weak verification of understanding, limited contextualization, and strong dependence on production conditions and individual mentors, while continuous learning is also unprioritized at an organizational level. This creates risks not only for individual performance, but also for the organization's ability to continuously develop and adopt new learning.

To address these challenges, the thesis proposes a structured context-adapted LMS for the final assembly environment, which is supported by microlearning, embedded verification, and the use of XR technologies. The suggested approach responds to the constraints of time, personnel, and production pressure, but also supports knowledge retention, accessibility, consistency, and scalability. Training with the use of XR technologies further provides safe and repeatable off-the-job learning, thus reducing the need for live production for skill acquisition and the need for supervision from the live production staff.

The main objective of improved competence development is ultimately to enable stronger operational performance. Having a more skilled workforce could reduce errors and quality deviations, may increase flexibility to handle variations and changes, and might improve troubleshooting abilities. This is expected to support a more resilient and adaptable production system, ultimately reducing disruptions, improving quality, and increasing organizational readiness for new technologies or restructuring. It further could create visible pathways for employees who wish to diversify their capabilities or switch positions, and a sense that they are being invested in.

However, these conclusions should be interpreted with the study's limitations in mind. The findings are based on a single case study at one company and one plant, and the proposed learning system was not tested nor implemented in a live production context. The results and conclusions therefore provide an indication of future competence and skill needs, as well as a suitable learning design, but does not empirically validate the outcomes.

6.1 Future Research

This study provides insights into future competence requirements and learning approaches in final assembly, but it does not come without limitations which points to areas in need of future research. For one, the study is conducted as a case study within one company and plant, making the findings context-specific. Future research would therefore gain from expanding the empirical base, i.e., by investigating multiple plants or companies, to increase generalizability of the results.

Further, this thesis validates its findings in a theoretical way, thus creating the need for empirical evaluation within real production environments - preferably with quantitative data. For this, a fully functional XR implementation is also needed for the learning system. This evaluation of the proposed solution would ideally be done in a longitudinal way to evaluate the proposed learning system's effectiveness on skill development, knowledge retention, and overall operational performance over time. Additionally, the feasibility of fully implementing XR technologies in an effective and cost-efficient way within the near future would also need to be further investigated. Finally, this thesis does not explore how learning and workforce development interventions should be implemented in a broader organizational or strategic context, which could therefore be of further interest.

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