D4.4. FUTURE SKILLS TRAINING CONTENT

UP-SKILLING FOR INDUSTRY 5.0 ROLL-OUT

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EXECUTIVE SUMMARY

This report (D4.4) is the fourth deliverable for Work Package 4 (Training needs assessment) of the Up-Skill project. Building on insights from D4.3 and ethnographic case studies, it reframes future skills mapping as an emergent, context-specific process shaped by interactions between people, technology, and organisational structures. The report begins by outlining current skills mapping approaches, highlighting their importance in anticipating future skills demand and identifying skills gaps. It then shows, through case studies, how new skills emerge as employees engage with technologies in practice, highlighting the critical role of managers in recognising and supporting these emergent skills. Finally, D4.4 proposes a participatory, co-creative workflow to help organisations—especially small and medium-sized enterprises (SMEs) and artisanal firms—identify, support, and develop the skills required for technological change. The approach does not aim to prescribe a universal list of future skills, but instead offers a process through which firms can surface tacit expertise, respond to shifting role boundaries, and co-design context-sensitive learning trajectories.

DESCRIPTION OF THE DOCUMENT

This document develops a structured yet adaptable workflow for co-creating future-skills programmes tailored to the real-world dynamics of industrial transformation, with a particular focus on SMEs and artisanal contexts navigating the shift toward Industry 5.0. Drawing on extensive case studies from the Up-Skill project, it provides practical guidance for designing learning interventions that respect local values, leverage tacit expertise, and foster resilient, adaptive capabilities across evolving work environments shaped by people, tools, and organisational change.

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1. INTRODUCTION

This report 'D4.4 Future skills training content' is the fourth deliverable for Work Package 4 'Training needs assessment' of the Up-Skill project. It approaches 'skills mapping' as an emergent, firm contingent phenomenon that is shaped by use and experimentation with technology. The report presents some context-specific evidence regarding the recognition and validation of skills, from when new technologies are implemented and new skills requirements are formulated to the implications for managerial ability to foster an environment in which human-machine learning and skills development can flourish.

By paying attention to the real-world dynamics of industrial transformation, with a particular focus on SMEs and artisanal contexts navigating the shift toward Industry 5.0, we found that workers are often able to build the skills necessary to operate new technologies and to unexpectedly adapt their abilities to older machines to extend their lives and integrate them with newer, more sophisticated machines. As shown in D2.2, where we mentioned the concept of 'mixed ecologies'—the coexistence of new and legacy equipment—new technologies are not only embedded alongside legacy systems, but are also integrated into established work procedures. Given that employees are often highly knowledgeable about how to operate existing machines, fix unforeseen problems, and asses the final quality of the products, human judgement and tacit expertise are a significant source of value on the shopfloor. The workforce's already existing skillset plays an important role also in determining how a new machine could complement human abilities, replace routine tasks or anticipate skills requirements that are difficult to predict beforehand. Equally important, though, is the role played by local culture and managerial mindset in recognising skills in use in the workplace, and therefore offering practical guidance for designing learning interventions that respect local values, leverage tacit expertise, and foster resilient, adaptable skills. In fact, previous research shows that skill demands are shaped less by technology itself and more by managerial strategies (Ashton et al., 2017), and shifts in required skills and occupational roles are primarily driven by organisational change (Greenan, 2003). Recognising and supporting these skillsets also requires management to understand the organisational conditions that promote a more human-centric approach—an orientation that Industry 5.0 encourages by indirectly advancing worker autonomy and addressing their evolving needs (Oeij et al., 2024).

Traditional future skills mapping exercises are insufficient to address skills shortages and promote reskilling and upskilling initiatives. These classifications are laudable and emphasise how crucial skill-related policies are for Europe. However, the development of new skills is not always linear and easily planned, and there is a risk that skill substitution will take precedence over skill enhancement. As recently reported by the Policy Department for Economic, Scientific and Quality of Life Policies (2024), "a single technology may result in very different skill needs depending upon the choices made by those charged with its introduction" (Hogarth et al., 2024, p.50). The European Union's (EU) quest for inclusive and sustainable change under the Industry 5.0 banner makes this viewpoint all the more pertinent. A more nuanced understanding of future skills—one that is understood as a process embedded in context and that is attentive

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to the politics of definition, and responsive to rapid change—is essential for equipping the workforce for the future.

1.1 Introduction to Future Skills

Debate and discussion on future skills has gained renewed urgency in light of rapid technological disruption, globalisation, and demographic shifts. As labour markets are reshaped by the diffusion of digitally based technologies, artificial intelligence (AI), and sustainability imperatives, the capacity to anticipate and cultivate relevant skills has become a critical policy and educational challenge (OECD, 2018; World Economic Forum [WEF], 2020; WEF, 2025). Future skills are framed as a rounded set of competencies encompassing cognitive, social-emotional, and practical abilities that enable individuals to navigate complexity and change. Drawing on the OECD Learning Compass 2030, these include *cognitive and meta-cognitive skills* such as critical thinking and self-regulation; *social and emotional skills* like empathy, collaboration, and responsibility; and *physical and practical skills* required for everyday functioning and well-being (OECD, 2018). Together, these domains reflect an integrated approach to skill development, supporting individuals in adapting to evolving societal and professional demands (OECD, 2019). This framing is underpinned by the assumption that the future of work and life will demand not only technical knowledge but also adaptability, emotional resilience, and lifelong learning as core capacities for thriving in uncertain, rapidly changing environments (Schleicher, 2018).

International organisations, national governments, and academic institutions have developed diverse frameworks to define and map future skills including a broad, evolving set of cognitive, social, digital, and sustainability-related competences to guide curriculum development, workforce policy, and organisational training strategies (Kotsiou et al., 2022). However, the future skills discourse increasingly reveals tensions. Frameworks often overlook the political and economic realities of *skill formation*, understood as the social processes through which capabilities are produced, recognised, and rewarded within specific institutional and labour market contexts (Busemeyer & Trampusch, 2012), particularly in relation to automation, managerial practices, and labour market dynamics. A growing body of critique (e.g. Berner, 2008; Pfeiffer & Suphan, 2015; Pfeiffer, 2016; Fernández-Macías et al., 2016; Hirsch-Kreinsen, 2016) calls into question the extent to which skills can in reality be identified, codified, and planned in advance, noting instead that many competencies emerge through direct engagement with technologies and organisational experimentation. This perspective challenges the assumption that future skills can be universally mapped or that their cultivation can be treated as a matter of technical design alone, detached from the social, organisational, and experiential processes through which skills actually develop.

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1.2 An Overview of Existing Future Skills Frameworks

While existing frameworks have made important advances in identifying key skill areas, a notable limitation lies in their breadth and abstraction. These efforts typically rely on extensive lists of broadly defined skills such as *critical thinking*, *digital literacy*, or *collaboration*—understandable given the ambition to address diverse sectors—yet often lack clear operationalisation or sector-specific guidance (Voogt & Roblin, 2012; Chalkiadaki, 2018).

Frameworks such as the WEF's *Future of Jobs* reports, the OECD's *Learning Compass 2030*, and the EU's *Key Competences for Lifelong Learning* all aim to identify and promote the competencies required for the future of work and learning, yet they differ markedly in focus, methodology, and practical applicability. The WEF's framework, based on employer surveys and labour market trends, emphasises short- to medium-term skill demands such as digital fluency, analytical thinking, and self-management. However, it has been critiqued for its limited representation of SMEs and for relying on broad skill categories that can obscure actionable insights (WEF, 2020). In contrast, the OECD's *Learning Compass 2030* presents an aspirational, education-oriented vision, emphasising transformative competencies like creating new value, reconciling tensions, and taking responsibility. While comprehensive, its lack of direct linkage to job roles and its reliance on abstract constructs make it challenging to implement and assess in practice (OECD, 2018). Meanwhile, the EU's *Key Competences for Lifelong Learning* outlines eight core competences—including digital competence, entrepreneurship, and civic engagement—intended for all citizens across the lifespan. Despite its policy relevance, the framework's generality necessitates national-level adaptation and does not account for specific labour market developments (European Commission, 2018). Although all three frameworks provide valuable high-level guidance, their conceptual breadth often leads to vagueness in implementation.

Terminological inconsistencies remain a challenge in this evolving landscape. The varied use of terms like *skills*, *competences*, *attributes*, and *knowledge*—with significant conceptual overlap—can complicate comparability and coherence across regions and sectors (Halász & Michel, 2011; Kotsiou et al., 2022). Despite their breadth, many frameworks still face difficulties in adequately representing SMES. SMEs often operate under distinct conditions and with different pressures compared to large corporations. In particular, they must deal with fluctuating resource constraints, informal learning processes, and volatile market demands—which are not sufficiently captured by mainstream future skills frameworks. Furthermore, existing frameworks rarely account for the political and institutional factors that influence which skills are prioritised or neglected. There remains room for deeper reflection on how skills are socially constructed—shaped by institutional definitions, managerial priorities, and policy negotiations—a line of inquiry that could enrich future iterations of these frameworks.

As such, the definition of what counts as a 'skill' is not merely descriptive but also a site of power, shaped by institutional agendas and what Jasanoff and Kim (2015) term

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'sociotechnical imaginaries'—collectively held visions of desirable futures enabled by science and technology. This recognition demands closer scrutiny of how 'skill' is defined, who gets to define it, and with what consequences. Far from being a neutral or technical classification, the designation of certain attributes or behaviours as 'skills' reflects broader institutional and sociopolitical interests. For instance, as Iskander (2021) demonstrates in her ethnography of migrant construction workers in Qatar, workers performing highly complex and embodied tasks were formally categorised as 'unskilled,' while managerial actors claimed ownership of narrowly defined, easily replaceable skills. Similarly, Braverman's classic critique (1974) exposes how technological change under capitalist imperatives often results not in 'upskilling' but in the redistribution of control and the fragmentation of work, whereby knowledge is extracted from workers and embedded into machines or managerial systems. In both cases, what is recognised as 'skill' depends not only on the actual competencies demonstrated, but on whose interests such recognition serves. Frameworks that view skills as isolated, measurable attributes often overlook their social context, disregarding tacit, affective, or collectively held forms of expertise. 'The social construction of skill' has increasingly shifted from being rooted in achieved qualifications toward being based on ascribed characteristics, such as personality traits or social comportment (Warhurst et al., 2017b). This shift repositions the power to define skill away from workers and peers and toward credentialing institutions, customers, and capital, with significant consequences for equity and labour market stratification. Consequently, defining skills is a political act, one that legitimates particular forms of knowledge and labour while rendering others invisible. This has serious implications for inclusion, equity, and innovation in future skills frameworks, especially when such definitions are operationalised into education policy, hiring systems, or technological design.

Another ongoing challenge in this space is strengthening the empirical grounding of proposed skillsets. While these frameworks offer a valuable orientation, critics have pointed to the limited evidence linking certain skills to measurable employment, productivity, or learning outcomes (Pellegrino & Hilton, 2012; Lamb et al., 2017). Moreover, the question of underestimation is central: many tacit, affective, or manual competences—particularly those found in skilled jobs or embedded in routine practices—are not adequately recognised in high-level lists. This points to a persistent undervaluing of embodied, experiential, and interpersonal capabilities that are difficult to measure but vital in practice.

Finally, a promising area for further development is the relationship between skills, technology, and organisational culture. While current frameworks may treat skills as isolated attributes, emerging research (e.g. Dhondt et al., 2022) shows that the way organisations adopt and implement technology is deeply shaped by their internal cultures—norms, values, and management practices. These cultural factors influence not only which technologies are chosen, but also how they are integrated into work processes, and thus, what kinds of skills are emphasised, enabled, or constrained. For example, an organisational culture that prioritizes efficiency may adopt automation in ways that streamline tasks but also limit opportunities for skills development or expression. In this context, technology does not simply enhance human capabilities;

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it can both enrich work by supporting complex tasks and reduce it to standardised routines. These dynamics—how organisational culture mediates the effects of technology on skill demands—remain underexplored in existing models.

1.3 EU Initiatives on Skills

The EU has embraced a holistic, policy-driven approach to skills development, placing lifelong learning and competences for sustainability and digitalisation at the core of its agenda. Key frameworks such as the *Key Competences for Lifelong Learning* (European Commission, 2018), *DigComp* (digital competences), and *GreenComp* (sustainability competences) exemplify this integrated vision. These frameworks acknowledge that competences encompass cognitive, social, and ethical dimensions, aiming to cultivate adaptable, engaged, and future-ready citizens.

The European Year of Skills (2023) further underscored this ambition, spotlighting the urgency of reskilling and upskilling in light of demographic shifts, digital transformation, and the green transition (European Commission, 2023). The EU's strategic direction is also shaped by the Industry 5.0 paradigm, which extends beyond the technology-centric model of Industry 4.0 to emphasize human-centricity, resilience, and sustainability in industrial transformation (Oeij et al., 2024). In this context, up- and reskilling are not merely instrumental responses to technological change but are viewed as levers for empowering workers and strengthening social cohesion.

EU forecasting mechanisms, particularly through CEDEFOP (2018), rely on quantitative labour market projections to inform vocational education and training policies. However, these projections only partially explain the complex dynamics of skills demand and supply. For example, empirical evidence indicates that in contexts of high unemployment, employers tend to raise qualification requirements—an effect known as "upskilling"—even when job content remains unchanged (Modestino et al., 2020). Yet, the assumption that labour supply shortages are a primary constraint for firms, particularly in manufacturing, is contested. Weaver and Osterman (2017) found that only firms requiring highly specialised skills experienced notable hiring difficulties, while most did not encounter significant mismatches, especially for generic skills like critical thinking or basic information and communication technology (ICT).

Beyond formal qualifications, non-cognitive attributes such as motivation, dependability, and willingness to assume responsibility play a crucial role in shaping workplace performance and the successful adoption of new technologies. As Cappelli (1995) argues, these attitudes—while partially shaped by early socialisation—can also be cultivated within organisational contexts, through practices such as structured role modelling, clear goal-setting, and inclusive team-based work systems. These insights suggest that a narrow focus on credential-based skill indicators may obscure the significance of psychosocial factors in workforce preparedness. Moreover, organisational changes—such as increased reliance on autonomous teams and flatter hierarchies—may unintentionally limit the institutional levers available to nurture these

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attitudes, potentially exacerbating disparities in worker development and inclusion (McClelland, 1961; Cappelli, 1995).

1.4 Why Existing Conceptions of Skills Merit Reconsideration

Existing frameworks have made valuable contributions to understanding and promoting skills development. However, they sometimes conceptualise skills as static inventories, which can limit our ability to fully grasp their emergent and evolving nature. In rapidly changing environments shaped by digitalisation and organisational transformation, skills often develop dynamically—through real-time engagement with technologies and adaptive problem-solving (Frey & Osborne, 2013; Kimbrough, 2025).

In addition, while much attention has rightly been placed on the supply side—what individuals need to learn—less emphasis has been placed on how organisations themselves must evolve. Many of the challenges in applying skills effectively stem not only from individual gaps but also from organisational structures, cultures, and practices that may not yet be aligned with new demands.

The definition of what constitutes a ‘skill’ is also undergoing transformation. Skills are not just technical assets—they are socially constructed and institutionalised in ways that can reflect existing norms and power structures (Warhurst et al., 2017b). As a result, certain valuable capabilities, such as emotional labour, caregiving, or craft-based expertise, may not always receive the formal recognition they deserve (Iskander, 2021). At the same time, some emerging skills may receive heightened attention due to prevailing trends, even when their long-term relevance is still evolving.

Finally, it is important to balance the emphasis on developing new competencies with recognition of the existing strengths and knowledge embedded in today’s workforce. While future-oriented thinking is essential, overlooking the value of current skills can hinder effective implementation and create resistance. We suggest that skill development efforts may benefit from being more co-produced with workers, emphasising mutual adaptation rather than top-down change.

1.5 Up-Skill Project’s Contribution to the Skills Discussion

Our project seeks to address these shortcomings by grounding skills analysis in the lived experiences of SMEs and sector-specific actors. By emphasising qualitative, context-sensitive inquiry, we foreground the emergence of tacit, relational, and situated competences that typically escape formal models. For instance, in sectors facing generational workforce challenges—where younger workers may resist entering roles associated involving ‘dirty hands’ or manual labour—the perception and valorisation of work itself becomes a key barrier to reskilling. Changing the narrative around vocational and technical work is thus as critical as defining the skills required.

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At the same time, our research underlines how firms often grapple with emergent skill needs that cannot be fully anticipated in advance. As our research shows, new technologies—whether Computer Numerical Control (CNC) machines, Manufacturing Execution Systems (MES), or Mixed Reality (MR) training platforms—frequently expose gaps in both technical and tacit knowledge only after implementation. This points to a model of skills development that is iterative and embedded in local problem-solving, where firms ‘tinker’ their way into new practices and competences. Moreover, the qualities firms increasingly value—such as motivation, adaptability, and the ability to ‘see the bigger picture’—suggest that attitude and context-awareness often matter as much as formal credentials. Recognising this, our findings show that companies may benefit from moving toward more inclusive and flexible hiring and training strategies, investing in people first and trusting that specific skills can be learned through meaningful engagement with evolving technologies.

Furthermore, our approach highlights how new competences emerge not only through job descriptions or training programs, but via continuous experimentation and improvisation at the workplace level. This dynamic, second-order orientation to skills—where learning is integrated into problem-solving and adaptation—offers a valuable complement to existing policy frameworks and formal training programs, enriching our understanding of how digital and green transitions unfold in everyday workplace practice.

1.6 Preliminary Conclusion

The aforementioned literature offers valuable reflections on how mainstream future skills frameworks might be further strengthened. Scholars have noted that these frameworks, while influential, may sometimes lack clarity in their conceptual foundations and empirical basis (Pfeiffer & Suphan, 2015; Warhurst et al., 2017a; Busemeyer & Trampusch, 2012).

Often, skills are treated as discrete and transferable attributes, which can be useful for certain policy and planning purposes. However, this perspective may underrepresent the ways in which skills are also socially constructed and context-dependent—shaped by organisational practices, cultural expectations, and institutional arrangements (Iskander, 2021; Berner, 2008). This can make it challenging to fully capture the complexity and diversity of skill development, particularly in settings such as SMEs and artisanal sectors that are adapting to digital and green transitions in highly context-specific ways.

At a more foundational level, this body of research invites us to reflect on how skills are defined, validated, and applied in practice. It highlights important questions around the social processes that underpin competence, the evolving role of management in fostering skill development, and the need to strike a thoughtful balance between strategic planning and emergent learning.

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In response, our project advances a qualitative, context-driven approach to future skills mapping, grounded in real workplace dynamics and oriented toward the lived realities of SMEs navigating digital and green transitions. This involves not just identifying new skills, but reshaping managerial cultures to better recognise and support the capacities already present in the workforce.

By capturing the emergent, tacit, and context-bound nature of skill development, our contribution addresses critical blind spots in existing models. This perspective is particularly vital in the EU's pursuit of inclusive and sustainable transformation under the Industry 5.0 paradigm. A more nuanced understanding of future skills—one that is embedded in context, attentive to the politics of definition, and responsive to rapid change—is essential for equipping the workforce for an uncertain future.

D4.3 established a System-Effectiveness lens that revealed how people, technology and organisation interlock differently in nine industrial contexts. It showed that moving toward Industry 5.0 is never a one-size-fits-all journey; it is a situated negotiation among legacy machines, tacit craft know-how, market pressures, ownership structures and community and organisational values.

D4.4 therefore refrains from prescribing ready-made training modules. Instead, it supplies a collaborative workflow by which local constellations of actors—employers, multi-generational employees, unions, craft schools, policy actors and researchers—can jointly translate the abstract insights of D4.3 into context-appropriate learning interventions.

2. EMERGING THEMES ON SKILLS FROM MAPPING HUMAN-TECHNOLOGY DYNAMICS

This section presents what we have found to be salient features of human-technology interactions and how skills emerge through engagement on site. As part of our methodological approach, *Task 4.5: Future Skills Mapping*—began by conducting a review of existing literature on skills mapping and future skills frameworks, aiming to identify their strengths, limitations, and underlying assumptions. To shed light on these dynamics across our cases, WP4 members collectively worked on developing a set of brainstorming questions in light of the insights from the literature review. By grounding our questions in both theory and field experience, we ensured that they could capture not only technical skill development but also the social, material, and cultural conditions in which skills take shape. The final version of these questions is used to encourage case-leaders (the ethnographers collecting data across the diverse cases in the Up-Skill project) to reflect on two key aspects: the influence of the socio-economic context on technological innovation, and the role of technologies in shaping future skills, particularly in the domains of managerial work, manual labour, and human judgement.

The content of this section is shaped around the insights drawn from the case-leaders' aforementioned responses to the developed questions and the discussions during a

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one-day virtual workshop we held in May 2025, which explored these emerging themes in greater depth. The full list of brainstorming questions is included in the appendix. Across our cases, it is clear that new skills and hybrid roles do not emerge in a linear or easily planned manner, but through situated engagement with technologies, local improvisation, and the evolving dynamics of production systems.

Traditional skills frameworks often attempt to catalogue future skills in advance—as if they could be predefined, isolated, and measured. However, our case study evidence strongly suggests that skills are not discovered in the abstract; they emerge through engagement with technologies, new tools, and shifting workplace dynamics. Mapping the future of skills, then, requires a different approach: one that accounts for the *social and material shaping of skills*: how new capabilities arise through the use of tools, local norms, and collaborative practices.

Furthermore, this process highlights the importance of *local skill mapping* in the sense that the emergence of skills is not simply a matter of individual acquisition or formal training but is deeply embedded in specific contexts of use and social interaction. As emphasised in the OECD's work on local employment and skills strategies (OECD, 2023), understanding how skills develop requires attention to place-based dynamics, including institutional settings, labour market needs, and the interplay between local actors. In our cases, we observed that skills emerge through the mutual adaptation between people and technologies, but also through their entanglement with local cultures, histories, and networks of practice. Workers often learned new ways of doing by drawing on tacit knowledge, peer interactions, and community norms, resulting in skill profiles that were hybrid, evolving, and context-specific. For instance, certain competencies only surfaced as meaningful or valuable when people collaborated across departments, experimented with new tools, or responded creatively to local constraints. The consequence of this emergence is that skills cannot be easily predicted or transferred without accounting for the situated, collective processes that shape them. In other words, future skill development is as much about social embeddedness and connectivity as it is about technological change.

The companies participating in our case studies span a diverse range of sectors, as shown in Table 1.

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Table 1 Overview of Companies and Their Sectors in the Up-Skill Project

Company	Sector / Description
Craft Key	Light engineering and repair
The Company	Food and oil processing equipment
Car Company	Global transport manufacturing
Lloyd	Capital equipment components engineering
TimelessSuits	Luxury clothing items
PrestigeInk	Luxury writing/desk items
IconicInteriors	High-end wood domestic items
LaFisarmonica	Costly wooden hobby items
GoldenBriar	Luxury personal wood items
Cornet Co	Costly metal hobby items

2.1 How skills emerge through personal qualities and intrinsic motivation

Across several case studies, recruitment strategies increasingly prioritised personal attributes such as adaptability, curiosity, and intrinsic motivation over formal qualifications. A site manager at Craft Key highlighted the necessity of recruiting people genuinely interested in practical, hands-on tasks—individuals whose hobbies or pastimes reflected a willingness to learn through hands-on experience—an essential quality in a context where most skills are developed on the job.

In The Company, workers with no formal qualifications were hired based on motivation, reliability, and interpersonal compatibility. One cleaner at The Company, for instance, transitioned into a machinist role due to their interest and rapport with colleagues—not prior experience. The career transition from cleaning to specialised

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welding as a machinist further exemplifies how personal qualities and informal skills can become highly valued. Her curiosity and social skills, developed while working across the site, led managers to recognise her potential and offer her a new role despite her lack of formal qualifications. Again, at The Company, one worker's transition from military service to a highly responsible role at the test rig further highlights this trend. His discipline, self-management, and ability to follow protocol—cultivated in the military—proved highly valuable in an industrial setting, even though he had no prior manufacturing experience.

In another example, Craft Key collaborated with a local education provider to give two students the opportunity to explore the capabilities of a new CNC machine. This placement served as a practical trial, allowing the students to experiment with the technology and demonstrate their potential. Following the trial, one of the students was offered a job. This proactive approach highlights Craft Key's innovative recruitment strategy, which values initiative and curiosity over formal credentials. In this case, successful employment resulted from hands-on experience rather than traditional hiring processes.

At IconicInteriors and GoldenBriar, similar trends are visible: personal qualities such as curiosity, initiative, and willingness to experiment strongly influence recruitment and internal mobility. For instance, at GoldenBriar, workers who display a 'bricoleur' attitude—showing initiative in innovating and experimenting—are highly valued and trusted, often becoming key figures in skill transfer within their teams. Managers across these cases increasingly recognise that an employee's attitude towards continuous learning and collaboration can compensate significantly for initial skill gaps.

Similarly, PrestigeInk and TimelessSuits have also emphasised personal attributes over predefined technical skills. At PrestigeInk, the owner values flexibility and eagerness to engage with new technologies and a dynamic work environment that encourages testing innovative ideas. At TimelessSuits, employee selection prioritises qualities that facilitate knowledge absorption and cultural fit with the company's artisanal identity, suggesting that personal qualities shape not only individual success but also collective organisational adaptability.

2.2 How skills emerge through using technology and learning by experimentation

Skills are not discrete assets; they are relational and emergent. Workers acquire them through 'bricolage'—improvising, adapting, and solving problems in specific contexts. In many of our firms, new skill demands only became visible after the introduction of new technology. For instance, Craft Key's experimentation with MR revealed that external technical support was unsustainable, creating a demand for internal upskilling which was not foreseen at the outset.

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At PrestigeInk, the company is working to codify the embodied knowledge of its workers, enhance internal knowledge sharing, and reduce reliance on individual judgement by implementing new machinery and digital interfaces. Similarly, at GoldenBriar, workers were required to explicitly articulate their tasks for integration into digital systems. This process revealed the complexity of manual procedures and uncovered the need for previously unrecognised forms of digital literacy, leading to improved understanding of task timing and coordination. These experiences highlight how technological implementations can expose tacit skills that were previously invisible to management—creating new visibility and appreciation for workers' expertise.

At Car Company, the introduction of 3D printing tools illustrates this point: rather than replacing machine-tool operators, the 3D printers were added to the range of machines available in the tool room. Machinists with an interest in 3D printing were able to experiment with these new machines, drawing on their existing skills to improve the finish of printed items, and using their knowledge of the company to develop novel applications for 3D printing machine parts, saving the company money and potential downtime by making components in house. These uses, and the associated skills, emerged in situ, not from a pre-planned skills forecast. Moreover, Car Company's engineers acknowledged the potential need for future cognitive augmentation of maintenance work using data analytics, which again underscores how skill demands evolve relationally through interaction with technology.

Similarly, at Lloyd, the laser spot welder (LSW) replaced some manual welding, but augmented skills at micro-scales—allowing precise manipulation under a microscope. However, the technology also required a different form of visual literacy and spatial judgement. Thus, what counted as 'skill' changed with the affordances of the machine.

A particularly rich example of the relational and emergent nature of skills comes from The Company's MES implementation. Although the system was introduced following standard project guidelines, it became clear in hindsight that new skill gaps had emerged—gaps that were not anticipated during initial planning. Specifically, managers realised that many workers lacked an understanding of how their individual tasks fit into the wider production system. This prompted reflection on the need for broader competencies: an ability to see how one's own work affects, and is affected by, the work of others across the production process.

These practices reflect emergent skill responses to both technological limitations and organisational gaps in communication and training, further illustrating how technology makes relational skill needs visible in practice.

2.3 How skills are revealed and recognised through technological breakdowns and the managerial gaze

An important analytical insight is that skills become recognised under certain social and technological conditions. For instance, a worker's patience and precision may

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remain invisible until a failure occurs—when a poorly machined part causes a breakdown. Tacit capabilities such as 'listening' to a CNC machine or 'feeling' the right torque during assembly only become visible when the machine fails or when performance degrades.

At Craft Key, challenges emerged with the MR implementation due to the failure of technologies to codify the tacit 'why' behind processes, demonstrating limitations in technology's capacity to capture experiential human judgement. For instance, the MR omits any explanation of why greasing certain areas is discouraged, leaving workers without a clear understanding of the associated risks or rationale. Similarly, managers at The Company underestimated the skill-demands of tasks like grinding, leading to a failed attempt at automating that work. At the same time, the failed attempt to automate the task, merely highlighted the previously hidden depth of skill and experience necessary for achieving the required quality of finish.

At Car Company, workers' tacit knowledge related to forklift driving—including nuanced spatial awareness and unspoken social coordination with colleagues—became apparent only when Autonomous Mobile Robots (AMRs) struggled to replicate these subtle but critical aspects of shop-floor interactions. Managers initially assumed these tasks were straightforward and automatable, again reflecting an underestimation of embodied, tacit worker expertise that became evident through technological shortcomings.

Additionally, at TimelessSuits, despite implementing sophisticated MES and Computer-Aided Design (CAD) systems to standardise production, managers acknowledged the persistent necessity of human artisanal expertise for ensuring product quality. Refined and subtle manual skills—such as appreciating the required fabric tension or achieving precise stitching—remained indispensable and often undervalued by digital systems, becoming clearly visible only in the final product and through the continued reliance on human quality checks and adjustments.

Similarly, as noted, Lloyd's LSW technology highlighted the intricate manual skills required at microscopic scales, emphasising that even advanced technological solutions continue to rely heavily on human judgement, dexterity, and spatial acuity. Hereby, dealing appropriately with intricate material challenges posed by new technologies also served as an important source of skill recognition by other workers and management.

2.4 How skills emerge through the enabling and constraining forces of technology

While technology is often framed as a tool to augment human ability, it can also constrain how skills are expressed. For instance, visualisation tools amplify sight but suppress other senses—such as hearing or touch—that are essential in skilled manual work. Across the cases examined, the relationship between technological affordances

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and human skills appears as a complex interplay: technology can simultaneously enable and restrict the expression of skill.

At Craft Key, MR experiments highlighted both the enabling and limiting dimensions of technology. MR improved clarity in instruction procedures, helping to streamline certain tasks. However, the need for external programming support created a dependency that restricted and slowed the firm's internal skill development. Management recognised that for MR to be genuinely beneficial, it would require internal skills not yet present within the organization. This demonstrates technology's dual role in augmenting capabilities while introducing new, and sometimes unwelcome, external dependencies. Similarly, the case of the lock-testing robot at Craft Key illustrates the limits of automation in replicating tacit human judgement. Initially expected to automate quality checks, the robot consistently failed to replicate the nuanced assessments made by experienced workers. As a result, skilled operators had to be reinstated. This underscores the often-overlooked limitations of automation in domains requiring subtle sensory judgements, reinforcing the ongoing relevance of embodied expertise.

At Car Company, collaborative robots (cobots) enhanced worker capabilities by anticipating human needs, handling precision tasks, and validating procedures through data capture. However, this augmentation came with a trade-off: it potentially reduced human autonomy by shifting aspects of judgement to algorithms. This case reveals how even supportive technologies can subtly constrain the discretionary space for human expertise. Further, simulation technologies used in the design of new electric vehicle (EV) assembly lines at Car Company abstracted worker roles into data points. This reduced complex physical and interpersonal skills to checklist validations. Consequently, opportunities for workers to influence design decisions were confined to predefined, digital channels—such as online suggestion boxes—rather than through participatory, collaborative design processes. This limited form of engagement highlights how digital mediation can restrict the scope of human input, even in processes intended to improve productivity and innovation.

This duality of technology also plays out in companies producing musical instruments, such as Cornet Co and LaFisarmonica. At Cornet Co, the potential use of cobots to support human labour—particularly in handling delicate parts—has been actively discussed. Proponents argue that cobots could improve precision and reduce physical strain on workers; however, concerns have been raised about their ability to cope with the irregularities inherent in one-off production tasks, which often require skilled human judgement and adaptability. This consideration underscores how technology can promise efficiency gains while simultaneously posing challenges to the flexibility essential to skilled craftwork. By contrast, LaFisarmonica took a deliberate stance in limiting the use of technology to preserve the expressive qualities of handmade instruments. After learning that a competitor had introduced a robot into sensitive manual production steps, the company chose to maintain manual shaping processes. Concerns about losing the subtle feel and sound of handcrafted components influenced this decision. These strategic constraints on technology adoption reflect

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LaFisarmonica's commitment to protecting the conditions for skill expression—particularly as a top-brand supplier to professional musicians.

At GoldenBriar, the implementation of digital tablets and MES systems brought more structured information to production processes, improving coordination and efficiency. Yet this standardisation also constrained workers' ability to adapt dynamically to unforeseen situations. Workers noted that digital tracking limited their capacity to exercise judgement and respond intuitively to unique challenges on the production line, exposing the tension between technological efficiency and human flexibility. This tension became especially pronounced in smoking pipe production, where the properties of briar can reveal flaws mid-process. In such cases, workers may need to return the piece to a colleague earlier in the workflow. Previously, this handoff was fluid and informal. With the new system, however, the process required identifying a code and placing the briar in a designated area—making it slower and less intuitive. Here, the digital system introduced friction into previously seamless, skill-driven interactions.

At Lloyd, the preference for a cheaper, smaller version of a waterjet cutter (WJC) over more advanced versions valued for their higher levels of precision at tiny scales, or ERP-CAD (Enterprise Resource Planning to Computer-Aided Design) integration, which enables streamlined coordination between design and production, illustrates how costly technology can act as a limiting force on skill emergence. While these alternative methods could improve product quality and workflow efficiency, financial constraints led the small firm to favour lower-cost options despite their limitations, or had made them refrain from acquisition all together, as was the case with the ERP-CAD interface. Consequently, workers continually had to compensate for inefficiencies—either by manually correcting finishing defects or by adapting workflows without systemic digital support. This scenario exemplifies how technological constraints are shaped not only by technical capacities but also by economic logics, directly affecting the scope of skill expression and material engagement in the workplace.

A similar dynamic was observed at The Company, where the MES system shifted quality-control responsibility to workers. While this initially appeared empowering, the simultaneous pressure to accelerate throughput reduced the time available for careful quality checks. Certain quality-assuring activities inevitably consume time—reducing machine uptime and negatively affecting the MES's visualised productivity metrics. Yet these activities often lead to longer-term savings and improved reliability. Workers ultimately found their judgement constrained by the very tools meant to support them. This further illustrates the dual nature of digital systems: they can extend responsibility but narrow the conditions under which that responsibility can be exercised meaningfully.

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2.5 How skills develop when management shifts from control to enabling learning

Our findings challenge the classical managerial model of "Plan–Do–Check–Act" (International Organization for Standardization, 2019), which presumes predictability, legibility, and full control. But as we have seen, the most relevant skills are often the least visible, least predictable, and least 'mappable' in advance. They emerge in context, through trial-and-error, improvisation, and tacit negotiation between workers, technologies, tools, and tasks. These skills are often invisible to management and workers find them hard to articulate in a way that is legible to skills mapping tools.

This calls for a new managerial ethic aligned with the principles of Industry 5.0—one not centred on control and automation, but on facilitation, trust, and the enabling of human potential. The role of managers is shifting from monitoring predefined skills to recognising and supporting emergent competences, particularly those not captured by checklists or dashboards.

At IconicInteriors and GoldenBriar, managers began to appreciate the contributions of 'bricoleur' workers—individuals who adapt technologies and mentor peers, even when their actions deviate from formalised procedures. At IconicInteriors, for instance, the Head of the Varnish Department plays an active role in refining and improving equipment. By identifying workers' concerns and negotiating solutions with the Head of Production, he enhances productivity through bottom-up innovation. This reflects a broader cultural shift, supported by the recently appointed Head of Production, who actively encourages employee involvement in technology adoption.

Similarly, at GoldenBriar, an employee with engineering and 3D printing expertise emerged as a bricoleur. Leveraging his technical knowledge and proactive mindset, he led the development of an in-house solution for mouthpiece production. He designed a prototype machine and partnered with a company in Eastern Europe to manufacture it—resulting in a custom lathe integrated with bespoke software to automate the process.

At PrestigeInk, managerial roles have shifted significantly toward facilitation, with leaders increasingly relying on digital tracking systems to identify productivity issues and reduce reliance on workers' intuition. For example, current efforts focus on cutting costs and minimising errors through the adoption of robotic machinery and the automation of production processes.

Car Company's introduction of an 'ideas hopper'—an online suggestion platform—together with the implementation of a health-and-safety/EDI (Equality, Diversity, and Inclusion) simulation in the new assembly line, also ostensibly signalled a move towards more participatory forms of innovation and employee engagement. However, in operational terms, these technologies introduce a significant layer of digital intermediation between employees and managers. Workers' contributions were increasingly mediated through structured data points—whether via the 80-point simulation checks or through depersonalised online suggestion submissions. This process effectively reduced the communicative space between employees and management to codified, symbolic interactions, thereby narrowing both the range of potential dialogue and the relational competencies required of managers. While this digitally distanced form of interaction appears to be viewed favourably by managers—at least anecdotally—this observation remains impressionistic, requiring further research and analysis.

At Craft Key, the shift towards managerial roles becoming data-driven highlighted new challenges. Managers acknowledged that managing data increasingly meant managing the firm itself. Craft Key's CEO pointed out the importance of involving workers directly in data utilisation, revealing managerial skills shifting towards facilitation, trust-building, and collaborative data interpretation rather than top-down control. A parallel shift was observed at Craft Key through the managerial practices, which became structured around continual assessment and development of employee competencies. This highlighted a new managerial responsibility: systematically fostering and supporting employee growth and adaptation to technological change.

Similarly, at The Company, the experience of MES implementation revealed that successful technology adoption requires managers not only to analyse data but to develop meaningful dialogue with workers about how technology reshapes their roles. Here, facilitation involves recognising workers' tacit expertise, fostering environments of mutual trust and collaboration rather than mere enforcement of new operational standards.

At Car Company, the use of cobots prompted managers to recognise that effective oversight requires cultivating a balance between technological precision and human adaptability. Managers acknowledged that their role increasingly involved supporting workers' capacity to interpret and respond creatively to technological prompts, underscoring a shift from controlling towards facilitating worker autonomy and judgement.

2.6 How skills emerge through context rather than predefined models of competence

Rather than mapping 'future skills' as a static list, this deliverable proposes a shift in focus: from skills as inputs to skills as outcomes of situated engagements. The key insight is that skills emerge through work, through interactions with tools, people, and organisational routines—and are recognised through socio-technical, not just cognitive, processes.

Thus, the future of skills policy must not only focus on education and training but also on creating workplace conditions where skills can emerge, be recognised, and be supported. This includes rethinking managerial roles, shifting from control to facilitation, and challenging dominant perceptions within the EU that skills can be pre-planned or entirely formalized.

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At TimelessSuits and GoldenBriar, MES and digital tracking systems revealed that skills recognition and development occur through situated, practical engagement with technology. While managers initially aimed to standardise production, they found in practice that skills emerged dynamically as workers navigated digital interfaces alongside manual processes.

At TimelessSuits, sewing and ironing machines are integrated into an Industry 4.0 system that links machinery to software monitoring task execution. This setup enhances efficiency and precision, as the machines can detect different fabric types and automatically adjust their finishing processes. In turn, workers have learned to complement their artisanal knowledge with the digital capabilities of these machines.

A similar dynamic is visible at GoldenBriar, where workers have adapted to using tablets while simultaneously processing pipes. The variable nature of briar wood often makes it difficult to follow standardised procedures, as flaws may require certain steps to be repeated. In response, workers requested changes to the digital interface that would accommodate such variability. This highlights the importance of skills policies that support continuous, context-sensitive learning rather than relying solely on predefined training programs.

In Lloyd, it became clear that even the most technologically advanced machinery, such as LSW and WJC, required situated human judgement to deal with unique and unanticipated production scenarios. Workers developed and refined their skills not through formalised training but through iterative experimentation and improvisation with technology, emphasising the need for policies and managerial approaches that nurture this organic, adaptive skill formation.

Car Company's experiences similarly suggest the need for contextual sensitivity in skill development. With technologies such as AMRs, the specific requirements and constraints emerged clearly only through actual implementation, challenging previous assumptions about automation feasibility. This highlighted the importance of creating organisational conditions that allow for iterative learning and responsiveness to context, rather than relying solely on prescriptive skills forecasting.

Finally, the cases of The Company and Craft Key illustrate vividly how skills emerge through practical engagement with new tools. Whether adapting to CNC machinery, MR implementations, or MES systems, workers' skills developed through hands-on experience, informal collaboration, and negotiation of technological affordances and limitations. These cases strongly advocate for flexible managerial and policy frameworks that appreciate skills as dynamically situated and relational rather than static and predefined.

By mapping the human–technology dynamics that shape skill formation, this project offers a grounded, empirically rich alternative to predictive models of future skills. It presents a nuanced view of how technologies do not simply demand new skills but also reveal, reshape, and sometimes obscure existing ones. A key area for reform lies in managerial orientation. Industry 5.0 calls for a conceptual shift—redefining

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management not merely as planning and oversight, but as a relational, ethical practice grounded in empowerment and proximity to work. Teaching how to 'manage differently' thus becomes a crucial task. Yet this vision stands in tension with a parallel trend: in many organisations, management is increasingly distanced from day-to-day operations, becoming more reliant on data dashboards, standardised metrics, and remote decision-making. The challenge, then, is to reconcile these trajectories—to cultivate forms of management that are both informed by data and meaningfully engaged with the situated realities of work.

3. HYBRID ROLES AND EVOLVING WORK BOUNDARIES: HOW TECHNOLOGIES RECONFIGURE SKILL DEMANDS

The diffusion of digital technologies frequently leads to the emergence of hybrid roles—neither purely manual nor purely digital, but combining oversight, adjustment, and coordination. This phenomenon is becoming visible at IconicInteriors, where technological integration is progressively transforming certain manual artisans into CNC operators and digital production monitors. Workers previously engaged only in manual craftsmanship now navigate complex interfaces, blending traditional expertise with digital fluency. This shift in role definition creates new demands for continuous learning, adaptability, and a combination of technical and artisanal knowledge.

A similar shift is observed at Car Company, where, as noted, the integration of 3D printing expanded machinists' responsibilities, allowing them to apply and extend their existing skills to additive manufacturing and in-house part production. These new competencies developed organically through day-to-day experimentation rather than formal training plans, highlighting how skill demands emerge through practical engagement with technology. This mirrors broader patterns observed by Barley (1988), who showed how workers adapt to automation by diversifying their skill sets—for example, machinists who learned to program numerically controlled tools in order to retain influence over production. Barley also noted that workers engaged in repair and maintenance often gain situational power, as their ability to interpret a machine's sounds, signals, or behaviour becomes essential to smooth operations. In both cases, automation does not simply deskill—it restructures skill, creating new demands and opportunities for occupational redefinition.

At Craft Key, similar hybridisation occurred through their adoption of advanced CNC equipment and experimentation with MR. Workers and managers discovered that operating these new machines required a fusion of manual understanding of materials with digital interface skills. For instance, after investing in MR technologies to test lock systems, it became clear that existing staff needed to develop new capabilities in digital manipulation and troubleshooting to effectively integrate these tools into their workflow. In the end, the workers and managers jointly developed workarounds to meet production requirements. As mentioned before, in one instance, two students were brought in on placement to explore the potential of the new CNC machine. One of them, after experimenting with the equipment's applications, was later hired—

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indicating how trial-and-error learning helped shape internal skill development and provided a practical solution to a skills gap.

In another case, during pilot testing of an MR technology, it became evident that while the MR system could support codified knowledge transfer, it lacked the ability to convey the tacit, experience-based ‘why’ behind certain assembly decisions—such as why grease was or was not needed in specific lock mechanisms. This limitation prompted workers and managers to adapt their onboarding and training strategies, reinforcing the importance of hands-on, interpretive learning alongside digital tools. This illustrates how hybrid competencies—technical adaptation, creative problem solving, and cross-functional communication—emerge as responses to unforeseen technology limitations.

At The Company, hybrid roles are evident in some workers’ jobs, which combine manual welding with tasks such as operating cutting equipment, performing maintenance on complex machines (like the disc washing system), and coordinating with various teams across the factory. Such roles illustrate how technological and organisational changes often result in job profiles that demand a breadth of cross-functional skills—spanning manual precision, digital literacy, and interpersonal coordination.

This transformation also extends to management. At The Company, the implementation of a MES shifted responsibility for quality control from management to workers, requiring them to think more systemically about their role in the production process. At the same time, some managerial functions became increasingly data-oriented, creating unexpected demand for system analyst–type skills at the management level. Many managers reported difficulties in interpreting and effectively utilising the large volumes of data generated by advanced shop floor systems. This challenge led to the growing involvement of systems analysts, who began assuming decision-making responsibilities traditionally held by managers.

This development signals the emergence of a new managerial archetype: either systems analysts will gradually expand their roles to include core management functions, or managers themselves will need to acquire technical and analytical expertise—effectively becoming more like systems analysts. In either case, this marks a reconfiguration of the managerial role, positioning it as a more technically oriented profession. This redistribution of tasks illustrates how technologies do not simply substitute skills but actively reshape the social organisation of work and expertise.

This pattern of hybridisation is echoed across several other firms. At Lloyd, as noted, the introduction of an LSW created new hybrid skill demands. The LSW allows for precision work at a scale smaller than manual welding, but it requires operators to work with a microscope and develop new forms of visual literacy and fine motor control. Workers now blend traditional welding expertise with these digitally augmented precision techniques, highlighting how digital tools augment rather than simply replace manual skills. Moreover, thanks to this technology, the LSW can help

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address the shortage of skilled welders and brazers—but only for this very specific application.

PrestigeInk also reflects this pattern. The owner emphasises the importance of working with employees who can flexibly engage with both new digital interfaces and traditional print production tasks. For instance, workers now operate advanced machinery and contribute to codifying previously tacit knowledge for use in digital systems connected to the MES. One example is the engraving process, which was once performed manually but is now done by machine and monitored by the worker.

A similar trend is visible at GoldenBriar and TimelessSuits, where operators increasingly use tablets and scanners, respectively, connected to MES systems. These tools help coordinate tasks, monitor quality, and interact with production tracking software—all while workers continue to carry out skilled manual work. These blended roles demand not only new technical capabilities but also a stronger understanding of system-wide processes, enabling cross-functional collaboration. At GoldenBriar, for instance, operators must both handle materials and interact with digital interfaces via tablets. At TimelessSuits, tailoring remains a manual task but is now complemented by digital tracking, as workers themselves operate the scanners—resulting in a hybrid role that combines craft with digital literacy.

Across these cases, we can also observe patterns that align with the hybrid role trajectories:

Hybrid Role 1: Operator → simple manager
At The Company and GoldenBriar, operators are increasingly taking responsibility for quality, tracking their own output, coordinating work with upstream and downstream processes, and interacting with planning systems. The role of operator is thus extending beyond execution into elements of scheduling, quality control, and self-management.

Hybrid Role 2: Manager → systems/data worker
MES and similar systems at The Company, GoldenBriar, TimelessSuits, and PrestigeInk are pushing managers into more data-centric work. Managers now need to interpret production data, engage with dashboards, and coordinate across systems—an emerging demand for analytic and integrative skills that were not previously part of shopfloor management.

Hybrid Role 3: Crossing boundaries into maintenance/debugging/improvement
At Craft Key and Car Company, we see operators being drawn into maintenance, fault diagnosis, and continuous improvement roles—especially where external support (for MR, AMRs, or CNC machines) is insufficient or too slow. Workers' willingness and ability to take on these cross-boundary tasks becomes a key enabler of successful technology use.

These patterns of hybridisation are not pre-planned, nor fully captured by traditional competence frameworks. Instead, they emerge dynamically as firms grapple with

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technology affordances, resource constraints, and shopfloor realities. This calls for flexible, iterative approaches to training and role development that can adapt as new forms of work continue to evolve. Ultimately, the emergence of hybrid roles reflects an ongoing rebalancing of skills across organisational layers—challenging firms to foster adaptable, cross-functional capabilities rather than relying on static job profiles.

This insight raises important questions about how to foster this kind of systemic understanding among workers. Suggestions may include making training days on the full production process mandatory and exploring whether tools such as competency matrices—already common for white-collar roles—might be helpful for supporting this broader development on the shop floor. However, managers also recognised that this shift may encounter resistance, as some workers prefer to focus on their immediate tasks. Thus, motivating workers to engage with ‘the bigger picture’ remains an open challenge.

The evolving nature of hybrid roles calls for a reconsideration of how work is structured, distributed, and developed across organisational layers. Echoing Barley’s (1996) observations on how technology reconfigures work practices, these cases show that new roles often emerge not through deliberate design, but as pragmatic responses to the tensions and affordances of new tools. This organic redistribution of responsibilities—where operators adopt quasi-managerial duties, and managers engage in systems work—highlights the fluidity of skill boundaries. It underscores the need for firms to move beyond static job descriptions and adopt more dynamic frameworks that accommodate role blending, boundary crossing, and emergent expertise.

To navigate this shift, companies may benefit from fostering ‘systemic awareness’ on the shopfloor—encouraging workers to see how their tasks link to broader workflows and goals. This could involve integrating cross-functional training, role rotation, and participatory design approaches into workforce development strategies. However, as the case of The Company suggests, there is often ambivalence or resistance from workers accustomed to narrowly defined roles. Addressing this will require not only technical upskilling but also cultural and organisational shifts that support learning, autonomy, and meaningful involvement in shaping evolving job content. Hybrid roles are not just a byproduct of digitalisation—they are a window into the new social architecture of work. At the same time, we recognise that not all workers wish to broaden their responsibilities or take on hybrid roles; some prefer to concentrate on the specific tasks in which they are skilled and expert. Forcing workers to diversify may threaten the retention of this depth of expertise, with unforeseen downstream costs in terms of quality and innovation. At The Company this was starkly evident in workers who stuck rigidly to their production cell, resisted trying other roles and even preferred to sit alone at lunch!

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4. FUTURE SKILLS MAPPING WITHIN THE SCOPE OF THE UP-SKILL PROJECT

The conceptual foundations for the D4.4 workflow are deeply informed by the findings of D4.3. Several key principles emerged, which shape how future skills mapping is approached within Up-Skill.

First, situatedness is critical. D4.3 showed that every case study combined unique business logics, technology maturities, and cultural traditions. This means that learning design must be rooted in the specific context of each enterprise, emerging in-situ rather than imported as an external solution. The resulting training must reflect local practice and preserve the distinctive 'accent' of each site.

Second, socio-technical reciprocity emerged as a core insight. In many cases, skill gaps were not the result of deficit of the workers, but symptoms of misaligned elements within the people-technology-organisation (PTO) system. Thus, any conversation about training must begin with mapping how skills, tools, and organisational routines co-evolve, rather than treating skill deficits in isolation.

Third, the principle of plural value is vital. D4.3 highlighted that firms often balance economic, craft, ecological, and community values in unique ways. Therefore, decisions about which skills to foster should not be driven solely by profit or productivity goals, but should integrate multiple value frames—including heritage, sustainability, dignity, and local community priorities.

Finally, the reality of dynamic roles demands attention. The case studies showed that 'role survival' and 'role redistribution' are often more important than creating entirely new job titles. Successful interventions should prototype how existing roles can evolve over time, ensuring that employees see a future for themselves in the transformed organisation. This means that role trajectory mapping must precede course design. Together, these principles call for a participatory, reflexive, and value-sensitive approach to skills mapping, fully aligned with the human-centric ethos of Industry 5.0.

5. EXISTING MATERIALS FOR THE FUTURE-SKILLS TRAINING

The European skills ecosystem offers a rich array of existing materials, frameworks, and pedagogical approaches that can be drawn upon to support the co-creative workflow for future-skills training outlined in the following section of this deliverable. These materials span formal qualifications, modular learning resources, digital platforms, and innovative pedagogical models that align well with the Industry 5.0 vision of human-centric, inclusive, and sustainable industrial transformation.

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5.1 Policy Frameworks and Competence Models

At the European level, several competence frameworks provide foundational guidance for future-skills training design. The *Digital Competence Framework* (DigComp; Carretero et al., 2017) offers a structured taxonomy for digital literacy across levels of proficiency, applicable to all sectors—including manufacturing and crafts—where digitalisation is advancing rapidly. The *Entrepreneurship Competence Framework* (EntreComp, 2016) supports the development of entrepreneurial mindsets and skills, especially valuable in SMEs and artisanal contexts. Additionally, The *European Framework for Personal, Social and Learning to Learn Key Competence* (LifeComp; Sala et al., 2020) addresses transversal personal and social competences, such as resilience, collaboration, and learning-to-learn, which align strongly with Industry 5.0's emphasis on human agency and adaptability.

5.2 Vocational Education and Training (VET) Materials

Europe's VET systems are undergoing active modernisation to incorporate future skills. The *Skills for Industry 4.0 Curriculum Guidelines* (2020), developed under EU initiatives, provide detailed content outlines for updating engineering and manufacturing programs, with emphasis on interdisciplinarity (e.g., mechatronics, digitalisation, and green manufacturing). Many national apprenticeship programs are now embedding digital and sustainability competencies as standard components, moving beyond traditional blue-collar profiles.

Recognition of prior learning (RPL; European Commission, 2022) and *Micro-credentials* (European Commission, 2020) frameworks also offer modular, flexible pathways for adult learners to acquire new competences aligned with evolving job roles.

5.3 Corporate and Industry-Led Training

European companies are significant drivers of future-skills development, offering a wealth of corporate training content that complements public VET provision. Internal 'corporate academies', e-learning platforms, and partnerships with universities are common, with content covering technical, digital, soft, and leadership skills. The EU's *Pact for Skills* (2020) encourages sectoral alliances where firms collaborate to define training needs and co-develop materials.

5.4 Pedagogical Innovations

New pedagogical approaches are increasingly influential. *Co-design methodologies*—such as Industrial Collaborative Educational Design (ICoED; Geraldes et al., 2021), in which workers, managers, and educators collaboratively defined training needs and

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created tailored upskilling pathways—are highly congruent with the participatory spirit of D4.4's workflow. Blended learning, MR-based simulations, project-based learning, and challenge-based formats (e.g., hackathons) are also growing in adoption.

5.5 Artisanal and Craft Sector Materials

In the artisanal sector, *bottega-style* master–apprentice models remain irreplaceable for transmitting tacit knowledge (Sennett, 2008). However, there is growing use of digital tools—3D scanning, online video archives, and digital design software—as complements for preservation and modernisation. The *Horizon Europe* (European Commission, n.d.-b) initiative explicitly calls for hybrid curricula blending traditional skills with digital and entrepreneurial competences.

5.6 Integration with Emerging Frameworks

Finally, the *European Skills, Competences, Qualifications and Occupations* (ESCO; European Commission., n.d.-a) taxonomy provides an evolving reference for aligning training content with labour market needs, though it requires continual updating to reflect emerging hybrid and tacit skill domains. Alignment with ESCO (European Commission., n.d.-a) and *European Qualifications Framework* (EQF; European Parliament & Council, 2017) can help ensure that materials produced through the D4.4 workflow are portable and recognised across Europe.

5.7 Summary

In sum, the European landscape already offers a substantial body of relevant materials for future-skills training—ranging from established competence frameworks to innovative co-created curricula. However, as highlighted in this deliverable, a critical gap remains: most existing materials are not sufficiently contextualised for the dynamic, situated, and relational skill dynamics revealed in the Up-Skill project's case studies. Therefore, the following D4.4 workflow complements existing materials by providing a participatory process that enables local actors to adapt and enrich these resources to fit their specific socio-technical contexts and value frames.

6. A CO-CREATIVE WORKFLOW FOR THE FUTURE-SKILLS TRAINING

While Europe already offers a rich ecosystem of future-skills frameworks (as discussed in Section 1) and a growing range of training materials (as described in Section 5), these resources must be embedded in situated, iterative processes to remain responsive to dynamic and context-specific transformations. As argued in the

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previous sections, the cross-comparison of case study findings from the Up-Skill project demonstrates that skill needs do not emerge from abstract predictions alone; they are co-constructed through daily interactions between people, technologies, and organisational routines. In many cases, the introduction of new technologies leads to subtle shifts in responsibility, autonomy, and role content—rather than immediate or dramatic changes in job categories.

Moreover, as manufacturing environments evolve with increasing digital integration, developing future-oriented skills requires a shift toward more participatory, reflexive, and human-centred approaches. Managers play a pivotal role—not only as facilitators of learning and change but also as active interpreters of how technology reshapes work and skill requirements in unpredictable ways.

In that respect, predefined frameworks must be complemented by participatory and situated learning processes that enable organisations—especially SMEs and artisanal firms navigating the transition to Industry 5.0—to detect, assess, and respond to skill shifts in real time. Managers are central to this process: not simply as implementers of training, but as stewards of organisational learning who interpret evolving work realities and guide the development of skills that reflect both technological demands and human capabilities.

Building upon insights from D4.3 and grounded empirical findings from the Up-Skill project, this deliverable introduces a co-creative, iterative workflow and toolkit that supports managers in mapping, anticipating, and developing future skills in ways that respect the tacit knowledge embedded in traditional manufacturing practices, while equipping workers for increasingly hybrid roles.

Rather than offering a static list of skills, the toolkit presents a structured yet adaptable process that empowers firms to:

- Identify how role content and responsibilities are shifting;
- Anticipate emerging skill needs linked to new technologies;
- Co-design targeted, context-sensitive learning pathways;
- Safeguard and amplify human expertise, particularly where automation risks deskilling or displacing embodied forms of knowledge.

The workflow encourages proactive dialogue across organisational levels, recognising that many of today's skill shifts involve ambiguous or contested terrain—such as unclear ownership of tasks introduced by automation, or the tension between digital 'sleekness' and on-the-ground complexity.

In this spirit, the co-creative workflow presented in Figure 1 provides a practical framework for companies and their partners to collaboratively translate systemic insights from D4.3 into actionable learning interventions, fully aligned with each firm's unique values, production realities, and human capacities.

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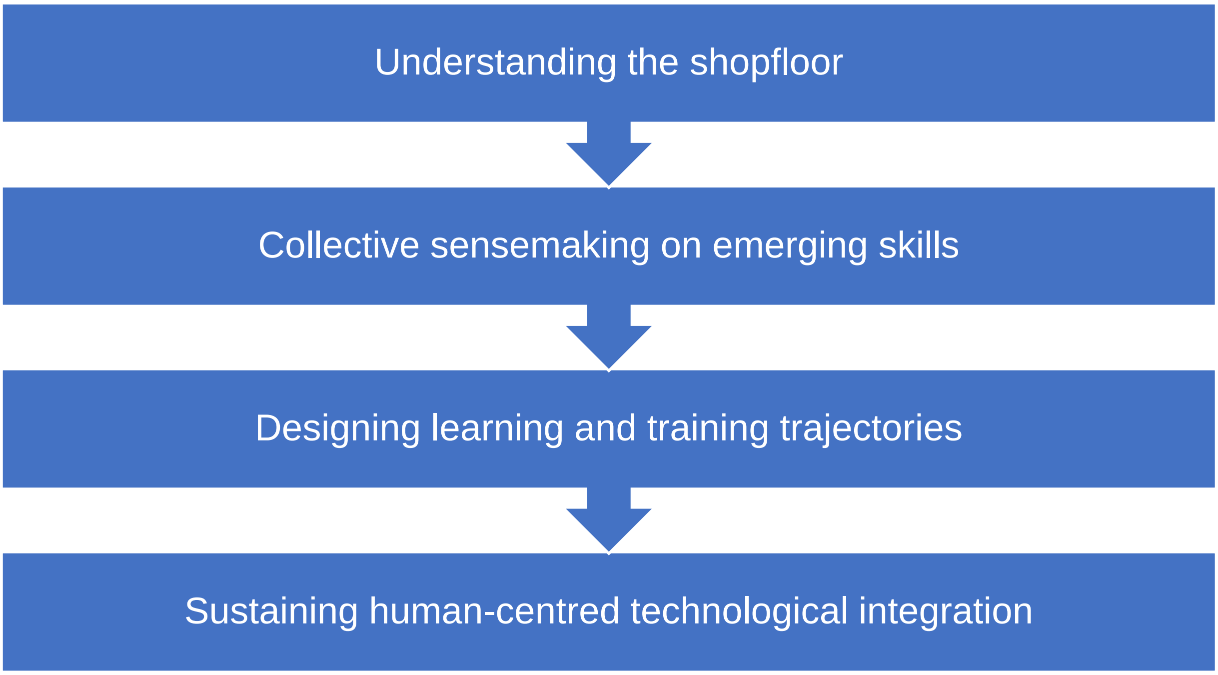

Figure 1 Up-Skill's Co-Creative Workflow for the Future-Skills Training

6.1 The Four-Step Co-Creative Workflow

The workflow comprises four iterative, interconnected steps designed to surface tacit knowledge, engage stakeholders in meaningful dialogue, and align learning strategies with both technological change and the evolving realities of work. Each step in the workflow is intended to be initiated, facilitated, and sustained by managers as active facilitators of skill development and organisational learning. Their leadership is essential not only for driving change but also for ensuring that skill development aligns with real shopfloor conditions, respects existing expertise, and supports a human-centred approach to digital transformation. Below we explain each of these four interconnected steps:

Step 1: Understanding the shopfloor

- **Engage directly with everyday work practices:** Observe how tasks are performed, focusing on informal skills, tacit knowledge, and real-time problem-solving beyond what systems capture.
- **Map social, technical and spatial dynamics and evolving role content:** Analyse how old and new technologies on the shopfloor interact with workflows, where responsibilities are shifting, and how workers adapt in practice.

- **Recognise and validate hidden forms of expertise:** Surface and acknowledge sensory, manual, and contextual skills that may be overlooked or undervalued during technological transitions.

Step 2: Collective sensemaking on emerging skills

- **Convene inclusive dialogues across organisational roles:** Facilitate conversations among workers, engineers, educators, and other stakeholders to explore how work and skill needs are changing.
- **Identify emerging hybrid skill profiles:** Understand how digital and manual skills are increasingly combined, creating roles that require flexible and layered capabilities.
- **Clarify role boundaries and new responsibilities:** Address ambiguities introduced by technology, especially in cases where maintenance, programming, or oversight roles are unclear or evolving.

Step 3: Designing learning and training trajectories

- **Co-create learning pathways grounded in real work:** Design development processes that reflect actual workflows, combining structured learning with experiential, on-the-job methods.
- **Integrate traditional and digital training methods:** Blend mentoring, peer learning, and practical exercises with tools like MR, augmented reality (AR), virtual reality (VR), or simulations to support context-sensitive skill building.
- **Adapt learning processes to changing conditions:** Build in flexibility to revise training content and methods in response to emerging technologies, worker feedback, and evolving tasks.

Step 4: Sustaining human-centred technological integration

- **Foster a culture of ongoing reflection and learning:** Encourage regular team-based evaluation of how technologies impact work, skills, and autonomy, using feedback to guide continuous improvement.
- **Safeguard human roles and meaningful expertise:** Monitor for risks of deskilling or alienation and redesign workflows where needed to ensure human contributions remain central and valued.
- **Model participatory and ethical leadership:** Demonstrate a commitment to transparency, trust, and shared responsibility in guiding technological adoption and skill evolution.

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6.2 Managerial Ethic and Responsibilities

Managers play a pivotal facilitative role, guiding processes of learning and skill evolution through active involvement, support, and recognition. They need to encourage and support workers' exploration and learning, facilitate open dialogue and collective sensemaking, recognise and validate emergent and tacit skills and overall champion a culture of learning and reflexivity across all organisational levels.

Therefore, the workflow reinforces a new managerial ethic for Industry 5.0:

- One that balances leadership responsibility with participatory practice;
- One that takes active responsibility for skill development, role evolution, and organisational learning—not just compliance or productivity metrics;
- And one that treats workforce capabilities as a strategic asset and source of innovation, not an afterthought.

The participatory dimensions of the workflow ensure that diverse voices shape the process, but ultimate accountability for creating enabling conditions—and for sustaining learning over time—rests with management. This is a crucial shift for Industry 5.0: moving beyond "Plan–Do–Check–Act" (International Organization for Standardization, 2019) control models to a more dialogical, reflexive, and human-centred leadership paradigm.

In summary, managers are responsible for:

- Understanding deeply the daily realities and evolving dynamics of the shopfloor.
- Leading collective sensemaking processes about skill requirements.
- Actively supporting the co-design and implementation of learning trajectories.
- Promoting an enduring culture of collaborative human-technology development.

By adopting this four-step workflow, SMEs and artisanal firms can effectively identify, cultivate, and sustain the skills necessary for thriving in the evolving landscape of Industry 5.0.

6.3 The Role of External Partners and Social Actors

The successful implementation of future skills development within the D4.4 workflow depends not only on what happens inside individual firms but on cultivating a broader ecosystem of collaboration. External partners—including educational institutions, trade unions, policymakers, and technology providers—play distinct and complementary roles in co-producing learning environments that are attuned to local contexts and socio-technical realities.

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Company owners and leadership teams contribute strategic insight, investment capacity, and long-term perspectives on business viability. They are often concerned with balancing innovation against operational risks, such as change fatigue, and maintaining brand integrity while adopting new modes of production. Their commitment is crucial for allocating time and resources to participatory learning processes. The multi-generational workforce, meanwhile, offers intimate knowledge of legacy machines, informal mentoring practices, and craft-based know-how that is often invisible but essential to production continuity. Their concerns typically centre on job security, dignity at work, and trust—especially in relation to generational divides in how technology is perceived and adopted.

Trade unions and works councils offer a collective voice and bring essential legitimacy to any transition process. Their role includes advocating for fair access to upskilling, protecting worker autonomy, and ensuring that new organisational structures do not undermine labour rights or increase precarity. VET providers and public agencies, in turn, contribute accreditation systems, public funding, and alignment with regional employment policies. However, their models may sometimes lag behind fast-evolving workplace realities, and thus benefit from being integrated into co-creative processes that reflect current shopfloor conditions.

Researchers and academic partners add interpretive tools, comparative analysis, and methodological rigor. Their task is to support innovation while safeguarding local specificities, ensuring that new training content does not abstract away from lived practices. Technology vendors and system integrators provide roadmaps and infrastructure but must also be included in dialogues about usability, interoperability, and real-world constraints. Their products do not operate in a vacuum; they require adaptation and feedback from end users to be effectively embedded into organisational life.

In sum, each actor brings not only value but also a set of priorities and concerns that must be actively negotiated. The D4.4 workflow encourages a balanced, dialogical approach to multi-stakeholder involvement—one that avoids one-sided control and instead fosters pluralistic governance. Effective future-skills mapping is thus not only a technical or pedagogical task but also a political and cultural one, requiring ongoing coordination across diverse institutional logics and positionalities.

7. FURTHER CONSIDERATIONS: SKILLS GOVERNANCE IN A HUMAN-CENTRIC INDUSTRY 5.0

A genuinely human-centric Industry 5.0 transition demands more than new training content or upgraded technologies—it calls for rethinking how skills are governed, who is involved in defining them, and how power is distributed in the process. The D4.4 workflow embraces this challenge by embedding skills governance into broader organisational and ethical commitments.

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Managers must recognise that sustaining this workflow is not a one-time effort but an ongoing organisational responsibility. They are accountable for ensuring that learning initiatives align with both operational priorities and the dignity of the workforce. This includes acknowledging tacit expertise, facilitating continuous dialogue, and refraining from delegating learning exclusively to HR or external consultants. Instead, managers must act as active participants in recognising emergent skills and fostering the organisational conditions in which these capacities can be supported and rewarded.

Yet responsibility must also be shared. Workers, unions, vocational education partners, and researchers all have vital roles in shaping content, surfacing local knowledge, and co-producing learning pathways. When these actors are treated as equal contributors rather than passive recipients, the result is a more grounded, equitable, and context-sensitive form of skills development. A key condition for this is parity of voice: in steering committees and training co-design workshops, mechanisms must be in place to ensure that worker perspectives—particularly those rooted in tacit, relational, and affective knowledge—are not overshadowed by managerial or technical agendas. Speaking time, agenda-setting, and decision-making processes must reflect this commitment.

Digital augmentation also introduces new governance concerns. As workplaces become increasingly mediated by digital systems—whether MES dashboards, wearable devices, or AI-assisted robots—new forms of data collection emerge. It is essential that these data practices respect GDPR regulations and are grounded in informed consent. Data about skill use or worker performance should be deployed to empower learning, not to enable punitive oversight. Similarly, when codifying craft knowledge, ethical considerations about attribution and ownership must be addressed. Artisans and community members who contribute to knowledge-sharing should be acknowledged, and steps must be taken to prevent the commodification of traditional skills without fair compensation or recognition.

At the policy level, the D4.4 workflow offers practical insights that can enrich broader strategic initiatives. Its outputs—such as role/learning trajectory maps and context-specific training artefacts—should inform the evolving Industry 5.0 Community of Practice at the EU level. They also hold relevance for ongoing updates to the European Skills Taxonomy (e.g., ESCO), helping to ensure that embodied, situated, and hybrid competences are adequately reflected. Additionally, the workflow is highly compatible with regional Smart Specialisation Strategies (S3; Foray et al., 2021), particularly in areas undergoing green and digital transitions. Embedding this approach within regional innovation clusters can create new leverage for scaling up while preserving contextual fidelity.

In these ways, D4.4 extends beyond organisational change to propose a new model of skills governance—one that is reflexive, participatory, and ethically grounded. It seeks not only to map future skills but to democratise how they are defined, taught, and valued. As such, it provides a critical foundation for ensuring that Europe's transition toward Industry 5.0 is not only technologically advanced, but also socially just and truly human-centric.

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8. CONCLUSION

Deliverable D4.4 reimagines future skills mapping as a relational, collaborative process grounded in the everyday realities of technological and organisational change. Through deep engagement with case studies across Europe, the report demonstrates that skills do not simply pre-exist or follow from technological adoption alone—they emerge through work, shaped by local values, social dynamics, and managerial practices.

Importantly, D4.4 positions skills governance as a shared responsibility, requiring active and equal participation from managers, workers, unions, educators, and policy actors. Future-skills initiatives, it argues, must move beyond technical design and workforce planning to address the deeper social processes that shape how skills are defined, valued, and supported.

The co-creative workflow introduced here enables organisations to respond flexibly to changing skill demands by making tacit capabilities visible, supporting the emergence of new roles, and embedding learning within real production contexts. It also calls for a new managerial ethic, aligned with Industry 5.0, where facilitation, trust, and co-learning replace control and standardisation as the guiding principles of workforce development.

By prioritising role survival, role redistribution, and the cultivation of hybrid, situated competences, this approach supports the evolution of existing workforces in step with technological change—helping to preserve the embodied expertise, cultural heritage, and human value that underpin Europe’s diverse industrial ecosystems. Complementing this, the workflow’s emphasis on governance, ethics, and stakeholder co-design ensures that future-skills mapping remains attentive to issues of power, equity, and inclusion.

In doing so, this deliverable provides not only a practical tool for firms but a conceptual foundation for rethinking how Europe prepares its workforce for an inclusive, sustainable, and human-centric industrial future.

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APPENDIX

Questions for D4.4 Future Skills Training Content

1. Context

a) How does the economic context of companies influence their technological innovation strategies and technology adoption processes?
b) What role do economic factors (e.g., market conditions, financial resources, competition) play in shaping companies' technology adoption decisions?
c) How do government policies and economic incentives influence firms' technological innovation and adoption strategies?
d) How do different ownership models (e.g., family-owned, state-owned, private equity, publicly traded) influence companies' technological innovation strategies?
e) Whether/how does technology adoption differ in SMEs compared to large enterprises?
f) How does technological adoption reshape the spatial organisation and materiality (e.g., physical space, workplace design, and tangible/intangible aspects of work) of workplaces and shop floors within companies?

2. Managerial Skills

a) To what extent are managers aware of the skills required by their workforce?
b) Whether/how do managers benefit from new/digital technologies to fill that awareness gap?
c) How do the managers make use of new/digital technologies to improve their managerial skills?
d) How do the managers perceive that the introduction of new/digital technologies may affect their managerial skills in the long run?
e) Is the management planning an organisational change and/or reconfiguration of certain roles, while introducing new/digital technologies?
f) How does the management's perception of workers' specialisation/expertise evolve in the process of introducing new/digital technologies?
g) To what extent are workers involved in the decision-making process?

3. Human-Judgement Skills

a) To what extent do workers' human judgement and expertise play a role in the production process?
b) Are the new/digital technologies that are/will be introduced substituting workers' knowledge and expertise? If yes, how?

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c) When does the new/digital technologies implemented augment human judgement?
d) To what extent does the management aim to transmit tacit knowledge of the workers to the new/digital technologies/machinery?
e) From the management's perspective, whether/how does codifying human judgement address to the shortage of new workers?
f) Whether/how are skill shifts transforming decision-making and judgement processes within teams? If yes, how do workers collectively respond to these changes?

4. Manual Skills

a) To what extent do the workers' manual skills and expertise play a role in the production process?
b) Whether/how are the workers involved in the maintenance and repair of their products?
c) Whether/how are the workers involved in the maintenance and repair of their machinery?
d) To what extent does the management aim to transmit embodied knowledge of the workers to the new/digital technologies/machinery?
e) When do the new/digital technologies replace and/or augment manual skills?
f) From the management's perspective, whether/how does automating manual skills address to the shortage of new workers?
g) Whether/how do workers augment, compensate for, or replace the limitations of technologies in the workplace?

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