D5.1 Developing the Teaching Factory 5.0. Phases 1, 2, 3.

WP5 Teaching Factories 5.0

Deliverable D5.1

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Document description

This document describes the activities to redevelop the Teaching & Learning Factory intervention in companies. Industry 5.0 is introduced to its components. The report describes the cases in which this test is developed.

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List of abbreviations

BRIDGES	Bridging Risks to an Inclusive Digital and Green future by Enhancing workforce Skills for industry 5.0
TF, LF, TLF	Teaching Factory, Learning Factory, Teaching & Learning Factory
WP	Work Package
I5.0	Industry 5.0
HR	Human Resources
AI	Artificial Intelligence
EMS	Electronics Manufacturing Services
AR	Augmented Reality
ROCC	Remote Operations Control Center
S/R/HC	Sustainability/Resilience/Human Centricity

Table of Contents

Executive Summary.

This deliverable presents the results of the activities carried out under Work Package 5 (WP5) of the Bridges 5.0 project, as illustrated in Figure 1. WP5 focuses on the development and operationalisation of Industry 5.0 (I5.0) principles within the framework of Teaching and Learning Factories (TLFs). It also includes the testing of these interventions in selected companies participating.

The interventions explored in this report are regarded as strategic mechanisms for enhancing the implementation of Industry 4.0 technologies, both within enterprise environments and training contexts. Within this deliverable, these interventions – referred to as augmented Teaching and Learning Factories (TLF 5.0) – are further enriched using the conceptual guidelines provided in Deliverable D1.1 (Oeij et al., 2023).

The report documents the design and deployment of TLF 5.0 interventions in corporate settings using an agile, iterative methodology designed to adapt to future needs. The process followed a structured, phased approach, guiding the pilots from the initial specification of training requirements through to design, implementation, evaluation, and finally the synthesis of conclusions and recommendations for future development. The first part of the report outlines the objectives and scope of WP5, followed by a discussion of the theoretical and practical underpinnings of the interventions. Particular emphasis is placed on how training systems can be tailored to reflect the core priorities of Industry 5.0. The report also considers job transformation at both the organisational and network levels within BRIDGES 5.0. Key elements, such as training templates and evaluation tools, are introduced alongside this conceptual framing.

The report presents four in-depth case studies, each exploring the implementation of TLF 5.0 in a specific company. Mondragon (Basque Country) examines the broader transition from Industry 4.0 to 5.0; Infineon (Austria) investigates challenges associated with automation; Kitron (Lithuania) focuses on the development of structured training systems; and Comau (Italy) explores the interface between human workers and emerging technologies. These case studies reflect the diversity of industrial contexts involved, offering insights into both shared challenges and context-specific adaptations.

The process of embedding Industry 5.0 elements into each organisational setting is described in detail, followed by a summary of outcomes and reflections on the effectiveness of the interventions. Supplementary annexes provide further background, tools, and supporting documentation.

Across the four pilot sites, the TLF 5.0 interventions proved both feasible and effective. Companies reported improvements in operational coordination, increased awareness among managers, and stronger engagement from the workforce. The pilots also led to measurable gains in both technical and transversal skills, with notable progress in adaptability, collaborative problem-solving, and systems thinking. Although organisational conditions varied across sites, the flexible, co-creative methodology of TLF 5.0 allowed each company to adapt the intervention to its own structure and priorities.

Crucially, the interventions contributed to the identification of an initial set of Industry 5.0 competences. These include technical skills such as artificial intelligence handling and lifecycle assessment, alongside broader competencies like adaptive decision-making and ethical awareness. These emerging competences offer a valuable foundation for future

curriculum development and policy design, reinforcing the potential of TLF 5.0 to support more human-centred, sustainable, and resilient forms of work and learning.

The accompanying diagram (Figure 1) illustrates how this deliverable integrates with other work packages and deliverables within the BRIDGES 5.0 project.

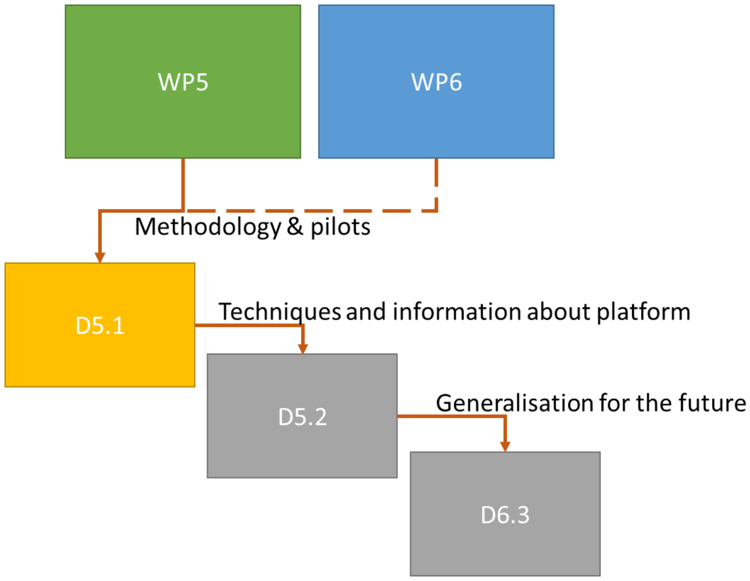

Figure 1: The documentation of work progress into deliverables: the WP5 case.

1 Introduction.

1.1 Objectives.

The primary objective of Work Package 5 (WP5) in the BRIDGES 5.0 project is to examine the governance of skill systems during the transition from Industry 4.0 to Industry 5.0. To support this goal, four companies have been selected to host pilot interventions, providing practical sites for experimentation and assessment. The insights gained from these interventions are intended to inform broader policy and facilitate the scaling of best practices at the European Union level.

This document offers a concise overview of the activities undertaken in WP5, with a particular focus on the implementation of company-based interventions. These pilots aim to embed Industry 5.0 principles into existing corporate training structures. To achieve this, WP5 adopts primarily experiential learning approaches, notably the Teaching Factory model, which emphasises real-world problem-solving through structured collaboration between industry and academia.

In addition to Teaching Factories, the project also incorporates Learning Factories and other innovative pedagogical methodologies that support experiential learning, such as gamification, which leverages game design techniques to enhance engagement and learning in non-gaming contexts. Together, these models form the Teaching and Learning Factories (TLF) framework, which serves as the conceptual and operational backbone of WP5.

- Teaching Factories (TFs) are defined as collaborative learning environments where practitioners from industry share their expertise with students, while students and academic staff bring theoretical knowledge into the workplace setting. This reciprocal exchange is structured as a continuous learning process, characterised by regular interaction and mutual problem-solving (Chryssolouris et al., 2016; Mavrikios et al., 2019). The central pedagogical emphasis of TFs is on problem-solving, critical thinking, and innovation in real-time industrial contexts.
- Learning Factories (LFs), by contrast, are controlled learning environments that simulate industrial settings. These spaces use actual tools, machinery, and workflows that mirror real factories, enabling participants to engage in hands-on learning of industrial techniques and concepts (Abele et al., 2017). The core focus of LFs lies in innovation management and the acquisition of technical competencies through immersive, practice-based learning.

While both concepts are grounded in industrial education, they differ in their didactic priorities. Learning Factories emphasise the simulation of industrial processes for teaching specific technical skills and methodologies. Teaching Factories, on the other hand, prioritise experiential learning through live interaction and the co-construction of knowledge between industry practitioners and learners. Both models rely on real-world challenges and collaborative projects to help learners apply theoretical insights to practical scenarios.

Within BRIDGES 5.0, the TLF 5.0 framework is extended beyond traditional goals. WP5 introduces additional objectives related to Industry 5.0 – particularly human-centricity, sustainability, and resilience – and examines the extent to which these values can be embedded into current training curricula. A key research aim is to identify measurable learning outcomes and evaluate their integration into existing educational and workplace systems.

Finally, WP5 is structured around six technical objectives, which guide its implementation and evaluation:

- O1: (MAIN objective) - To integrate I5.0 (pillars) in training systems, primarily through TLFs.
- O2: (PRIMARY objective) - To check skills for I5.0 and review attitudes of trainees.
- O3 (PRIMARY) - To couple business and learning ecosystem[1] aspects and training in job transition.
- O4: (secondary) - To study organisational and social topics.
- O5: (secondary) - To consider humans (trainees) in the co-designing environment.
- O6: (secondary) - To study aspects of future generalised interventions and extract respective practices for companies[2].

WP5 follows the guidelines of the D1.1 framework, meaning that the design of new jobs is conditioned by quality of jobs criteria. Job redesign requires a sociotechnical perspective. WP5 also includes lessons about the learning organisation, linked to D2.1 (Greenan et al, 2023).

As the first deliverable of WP5, D5.1 describes the procedure of designing and implementing the "augmented TLFs" for companies (TLF 5.0). This is done incrementally as activities progress throughout the project.

1.2 A note on intervention.

Training and Learning Factories (TLFs) are designed as targeted interventions intended to transform conventional work practices into configurations that are compatible with Industry 4.0 paradigms. The evolution toward TLF 5.0 denotes a strategic shift: interventions now encompass the creation or modification of training procedures that aim to operationalise the principles of Industry 5.0 within organisational settings.

Each intervention establishes learning trajectories that build upon the enriched conceptual framework of the Teaching Factory model. The overarching objective is to examine the concrete implementation of Industry 5.0 principles – such as human-centricity, resilience, and sustainability – within real-world company environments. As part of WP5, these interventions will assess and quantify companies' transitions from Industry 4.0 to Industry 5.0, with particular focus on the dimensions outlined in Section 2 of this report.

In this context, we employ the term intervention in two distinct but interrelated ways:

- *Pilots as Organisational Training Interventions:* We refer to organisational training systems, methods, and processes as interventions when they are intentionally designed or adapted according to the TLF 5.0 framework. These interventions aim to systematically alter learning outcomes, thereby serving as pilot implementations of the broader TLF model.
- *The Intervention Study as a Meta-Analytical Process:* In parallel, this report also constitutes an intervention study. Here, the focus shifts from the implementation of

[1] Mainly for WP6, but some aspects could be considered also herein.

[2] The perspective of companies is an extra link to D1.1 (mainly Annexe 5 therein), in addition to the ones mentioned further below in the document. For more details, in Annexe 1 herein, a schematic has been provided.

training systems to the refinement of the TLF-training methodology itself. This study investigates the content and pedagogical approach of the TLF intervention model, proposing new values and methodological adaptations aligned with the demands of Industry 5.0.

It is important to distinguish clearly between these two conceptual layers. The term intervention study is used exclusively to refer to the research and methodological development discussed under the second point above, whereas intervention or pilot refers to the practical implementation of TLF frameworks in organisational contexts.

1.3 How to read this research note?

The report consists of seven sections:

- **Sections 2 and 3 are related to the framework description**. The framework is generic enough to facilitate future generalised interventions, while also covering the diversity of case studies presented within the project pilots. It is rather a meta-framework allowing its continuous improvement and modification as per the needs of the era. The comparison between the current and future statuses of the companies will also be drafted. These Sections were delivered in Month 12 of the Bridges 5.0 project.
- **Section 4: Specifications and initial design** – This section outlines the entire pilot process, from the potential delivery of materials to the evaluation and extraction of practices. This Section is delivered in Month 16 of the Bridges 5.0 project.
- **Section 5: Design and Implementation of the Pilots** – This section regards the brief reporting of the procedures, along with Section 4, and will include the material that will affect the feasibility of I5.0 integration in these training pilots. This Section was delivered in Month 32 of the Bridges 5.0 project.
- **Section 6 contains the evaluation of results** – The outcomes of the pilots, such as upskilling, are evaluated. The pilots will be compared on several dimensions. At the same time, the practices that will feed the future policies will be extracted. This Section was delivered in Month 32 of the Bridges 5.0 project.
- **Section 7 discusses overall outcomes.**
- The **Annexes** contain complementary material that is secondary to the WP5 procedures, yet crucial to making the interventions future-proof.

Noteworthy points about this Deliverable include:

- It exists in parallel to D6.1, which regards associations and networks, instead of companies, so some material between the two is expected to be common and/or similar.
- It is followed by D5.2 and D6.3, which both regard conclusions for the future.
- The deliverable follows the Bridges 5.0 framework, so definitions and material may precede this, mainly in D1.1.

2 Setting the framework for training interventions in companies.

2.1 Introduction.

In this section, we look closely at the core concepts of the intervention study. These concepts are:

- The Teaching Factory: What is it?
- Industry 5.0: How can it be integrated into the training (educational in general) procedure?

For the concept of Industry 5.0, we refer to deliverable D1.1 of the Bridges 5.0 project.

2.2 The Teaching Factory.

Task 5.1 of the BRIDGES 5.0 project centres on the development and implementation of the organisational intervention known as the Teaching Factory (TF). This initiative represents a key research strand within Work Package 5, addressing the evolving relationship between industry and training in the context of the digital and green transitions promoted by Industry 4.0 and Industry 5.0 strategies. A central premise of Industry 4.0 is the reintegration of industrial production and skills development. In recent years, numerous efforts have been made to redesign pedagogical approaches in both corporate training systems and formal education. These efforts can be observed at two interconnected institutional levels:

1. Company-Level Innovations: Initiatives that redesign training practices to better align with the operational realities of contemporary workplaces.
2. System-Level Reforms: New agreements and partnerships among stakeholders in the educational field at regional and national levels, aiming to adapt curricula and certification systems to emerging competence needs.

Educational theorists argue that the development of future-oriented skills can only be effective if action-based (experiential) learning is meaningfully combined with comprehension-based (theoretical) instruction (Pittich et al., 2013). As a result, increasing attention has been paid to creating more practice-based learning environments. Within this context, the Teaching Factory has emerged as a model that integrates learning and production in real or simulated industrial settings. Nevertheless, the systematic evaluation of these interventions remains underdeveloped. Evidence on outcomes is limited, partly due to the inaccessibility of such company-level training environments (Nick et al., 2019; Pittich et al., 2020; Lensing, 2016). Those initiatives that are embedded within companies and require worker engagement are generally classified as Training Factories. However, a structured assessment of how such interventions contribute to the twin transition – digital and ecological – is still lacking.

Within the BRIDGES 5.0 project, we collaborate with partner organisations to design or adapt curricula for training programmes in four selected companies. These interventions aim to integrate Industry 5.0 principles – such as human-centricity, sustainability, and resilience – into everyday training practices. The process includes:

- Documenting the didactic methods employed,

- Evaluating their relevance in collaboration with workers and company representatives, and
- Assessing their potential for broader application.

The pilot training programmes developed in the four companies will also be introduced to the broader network of enterprises involved in BRIDGES 5.0. This step aims to extract a guidance framework that can inform scaling and policy uptake at the European level.

2.3 Building the Conceptual framework for Industry 5.0 interventions.

Industry 5.0 (I5.0) offers a pathway for meaningful job transformation. There is an ongoing and well-documented demand for workforce skills to adapt in response to technological and organisational changes (Grabowska et al., 2022; EU, n.d.; Poláková et al., 2023). New machinery and digital tools in production environments increasingly require a hybrid of digital competencies and hands-on experience. Furthermore, effective communication between interdisciplinary teams within companies is vital for enhancing problem-solving, critical thinking, and decision-making (World Economic Forum, n.d.). Perhaps most crucially, the continuous training of employees in new technologies – alongside the development of personal and social skills – emerges as a cornerstone of job transformation. With this approach, employee empowerment can be enhanced, particularly for vulnerable groups such as low-skilled or older workers. Ongoing training enables these employees to adapt more readily to emerging tools and workflows, thereby maintaining competitiveness within the organisation. It also enhances self-confidence, allowing individuals to take on new challenges and responsibilities, which contributes to improved job satisfaction. In turn, this fosters a culture of innovation and growth within the workforce, bolstering the organisation's overall adaptability to market dynamics and technological developments.

In BRIDGES 5.0, job transformation is studied in relation to both **business transitions** and **network transitions**, as illustrated in Figure 2. The framework for WP5 acknowledges that job-related changes are not solely the result of internal organisational processes but are also shaped by broader structural transformations. As such, two interlinked perspectives must be considered: business transformation and human education.

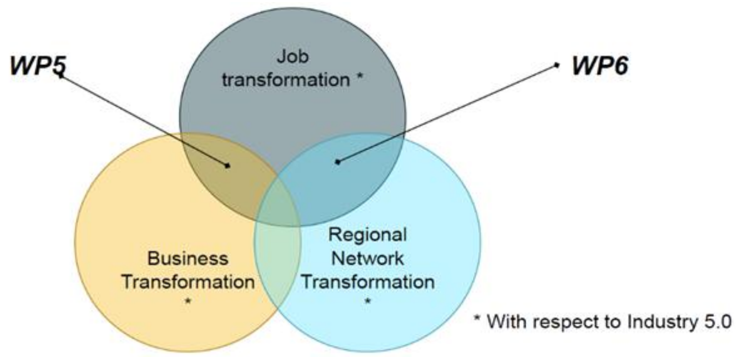

Figure 2: Generalisation aspects of the intervention.

The following figure illustrates how the framework integrates I5.0 principles. The three foundational pillars of I5.0 – **human-centricity**, **sustainability**, and **resilience** – are represented as vertical columns. A fourth element, **the social dimension**, is introduced as an additional parameter. This dimension is essential, as it captures the broader societal and regional context in which jobs are embedded, including interactions with local ecosystems. This is a distinctive contribution of BRIDGES 5.0 and adds value by addressing job transformation not only at the firm level but also in relation to its social embeddedness.

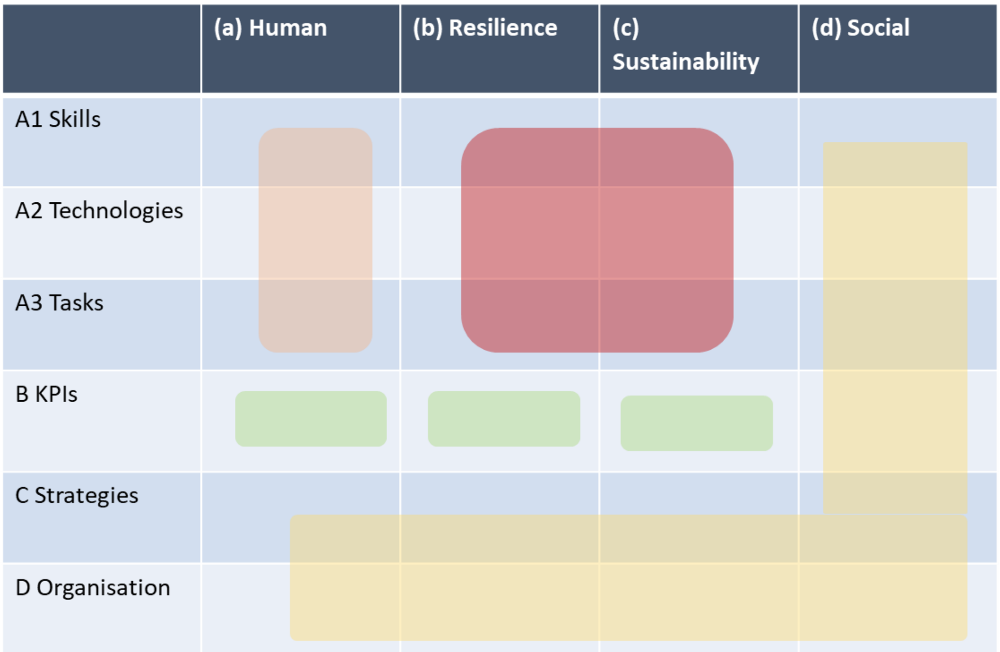

Figure 3: The template table / the current form of the (meta)framework.

The first three rows – skills, technologies, and tasks – are considered job-related criteria. These are directly tied to human capacities within the organisation and contribute to improving workers' positions. Skills, as a form of human capability, are the foundation of individual performance and productivity. These, in turn, influence organisational resilience and sustainability since well-executed tasks contribute to business continuity and competitiveness. This tripartite model of job characteristics (skills, technologies, tasks) is well-established in the literature (Acemoglu & Autor, 2011) and is widely recognised as a key framework for understanding how training affects job performance.

The remaining rows in the template relate to organisational practices and structures. Here, sociotechnical design principles (van Haastrecht et al., 2021) become relevant. The elements of *processes*, *people*, and *technology* are intrinsic to this design logic, as technologies have been considered in the table as a row and human centricity as a column. At the same time, *goals* and *culture* can be partially aligned with strategic and operational performance indicators (as a row of the table).

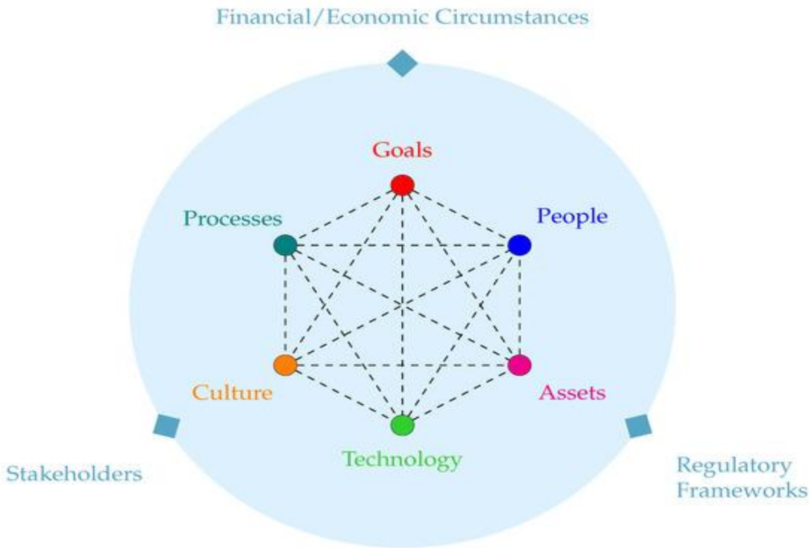

Figure 4: The sociotechnical model. Source: van Haastrecht et al., 2021).

Key performance indicators (KPIs) are employed to assess the progress of industry transformation along the three I5.0 pillars. They serve both quantitative and qualitative functions, reflecting productivity, alignment with organisational goals, and the integration of human-centric, sustainable, and resilient practices. KPIs should be carefully chosen to be realistic, achievable, and sufficiently ambitious to encourage improvement. Moreover, they must be continuously monitored and updated in response to changes in the organisational or external environment.

Organisations also need to update their strategic orientations in line with I5.0 principles. This involves revisiting social and human-centred strategies that may have been previously under-emphasised. These revised strategies could include new dimensions such as:

(i) reduction of arduous and/or repetitive work
(ii) increased job autonomy
(iii) broader job scope
(iv) inclusive opportunities for on-the-job learning and development
(v) delegated decision-making and self-managed teams
(vi) reduced functional demarcations
(vii) adoption of coaching-style management
(viii) employee-driven innovation

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From an organisational perspective, companies are shaped by two primary structural dimensions: the **company structure** and the **product life cycle** (Fuertes et al., 2020; Veile et al., 2020; Liu et al., 2021). The product life cycle begins with market research and design, progresses through production and delivery, and ends with post-market support and disposal. Each stage involves different departments and requires cross-functional collaboration. This process is crucial in understanding how job functions evolve and can be used as a reference in organisational modelling (model shown in Figure 5).

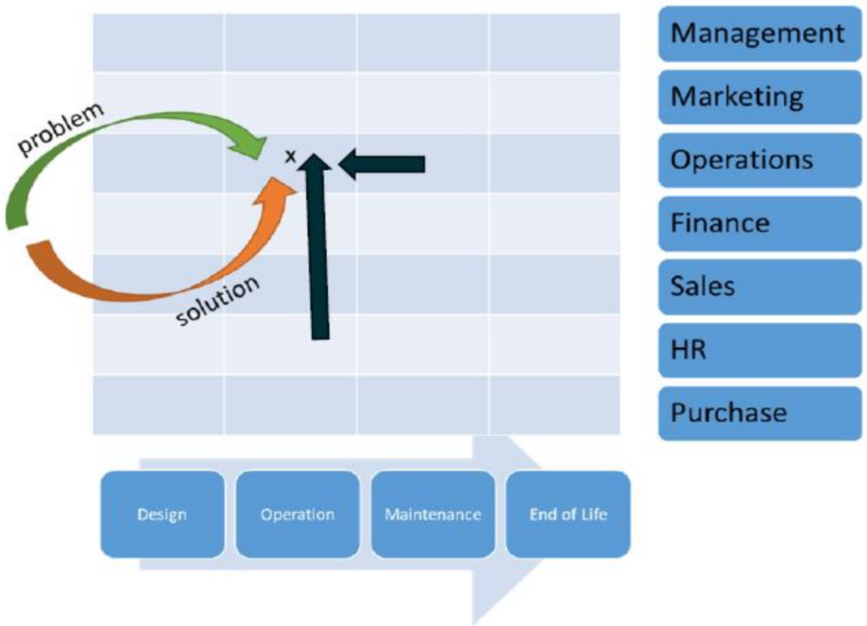

Figure 5: Integrating organisational topics other than training: the company case. The arrows indicate the transfer of topics from other departments to production-related problems.

The template table, which uses colour coding, illustrates how different categories are grouped to facilitate the design of I5.0-related training interventions. The colour scheme identifies the minimum required information to initiate an intervention. While this system is useful for speeding up the definition process, it is recommended that all cells be completed to ensure a more comprehensive intervention design.

Some categories – such as social, strategies, and organisation – are grouped together, as their relationships with the I5.0 pillars are less direct. Nevertheless, these elements are critical to both project outcomes and industrial practice. Other categories – resilience and sustainability – are grouped under job-related criteria, as they often influence product development and business continuity. These groupings offer an opportunity to emphasise human centricity as an integrative pillar further.

Technologies, including Artificial Intelligence (AI), can support both sustainable and resilient practices while also shaping job functions. Job-related criteria often influence one another: a technician's decisions may impact not only production efficiency but also job design and product quality. While KPIs are examined independently from the pillars, their use reinforces the need to assess all pillars simultaneously, even in cases where technologies or investment strategies may not be equally developed across the board.

2.4 Components of the framework.

Evaluation can encompass a wide range of topics and is typically categorised as either formative or summative (AESE, n.d.). Formative evaluation provides feedback to improve programme design and implementation, whereas summative evaluation assesses whether the programme has achieved its intended objectives.

In line with the objectives of WP5 – particularly Objective 1, which addresses the feasibility of the interventions – the current interventions require, at minimum, a summative evaluation framework. This framework focuses on the following key dimensions:

- upskilling,
- ease of intervention,
- usefulness towards generalisation,
- implications for organisational changes,
- implications for mentality changes,
- the engagement of the company in terms of practices.

Throughout the project, partners will remain mindful that the target group must acquire updated competences to keep pace with technological developments. Each job requires a combination of hard skills and soft skills.

- Hard skills are typically gained through formal training or on-the-job experience. In the context of BRIDGES 5.0, examples include the ability to operate advanced technologies, resolve complex production-related issues, or analyse and interpret data (see Table 1).
- Soft skills refer to personal and interpersonal competences, often acquired informally. These include teamwork and collaborative decision-making, creativity, adaptability, and cross-functional flexibility – particularly valuable in dynamic production environments.

	Human Centricity	Resilience	Sustainability	Social aspects
Hard	Ability to handle Explainable AI Data interpretation	Capability to handle IoT-related data and interpret maintenance statistics	Ability to handle Lifecycle Assessment analysis	
Soft	Analysing, evaluating, synthesising, and reconstructing information Recognising new patterns and applying them in new contexts Fostering imagination and creativity Multitasking	Persisting despite challenges, obstacles etc. Problem-solving and decision making Flexibility/ adaptability	Ecology concern	Team working Understanding the interpersonal dynamics and behavioural implications of human interactions Resolving conflicts

Table 1: Examples of skills that could be adopted in the template matrix.

In addition to adopting a new mindset, technicians must embrace new methodologies and acquire updated knowledge to enhance their decision-making capabilities when addressing challenges that affect company operations and resilience (Fadwa et al., 2023). Should the participant profiles or skill requirements change significantly during implementation, it may be necessary to revise the top line of the training framework template – shifting the focus from skills to competences.

To support this approach, WP5 adopts a hybrid skills taxonomy, informed by:

- The BEYOND 4.0 model, which focuses on human-centricity (Behrend et al., 2023)

- The ESCO classification (European Skills, Competences, Qualifications and Occupations)
- The GreenComp framework for sustainability competences
- Insights from related initiatives, including the LAMARTRA project and the IndustriALL trade union network.

In addition, resilience-related skills have been incorporated into the taxonomy (Kotsios, 2023). The localised representation of these skills is shown in Figure 6, and a preliminary classification is provided in Deliverable **D6.1**. The final classification, along with the mapping of relevant practices, will be presented in **D6.3**.

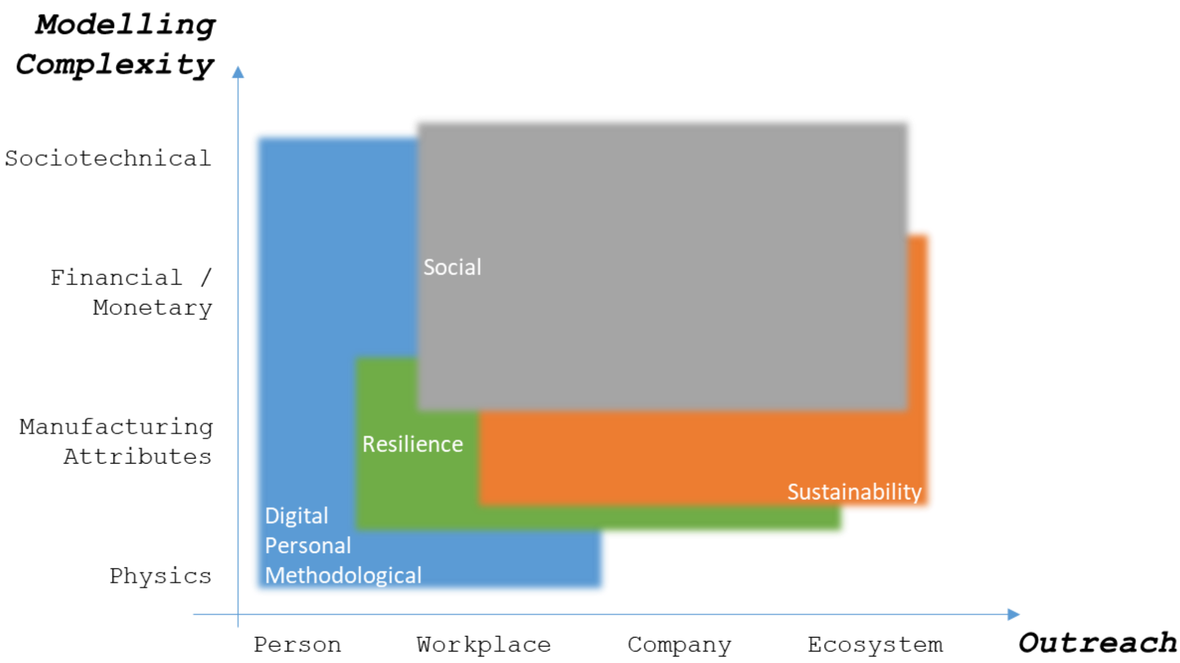

Figure 6: Tentative skills localisation in an abstract 2D space.

With respect to technology and innovation, the Table 2 shows some examples of technologies like AI, additive manufacturing, etc. and how they address the pillars of I5.0. Research is still very limited on how positively or negatively the pillars affect production and industry. However, a positive effect is expected on production time, saving materials and energy in the production of high-value products, human skills, etc.

In terms of technology and innovation, the technologies – such as artificial intelligence (AI) and additive manufacturing – and how they relate to the three core pillars of Industry 5.0 (human-centricity, sustainability, resilience). Although empirical research is still limited on the specific effects these technologies have on industry, early indications suggest positive contributions in several areas, including:

- Reduced production time
- More efficient use of materials and energy
- Enhancement of human capabilities
- Production of high-value and customised goods

To summarise the intervention logic using the OECD results chain framework (OECD et al., 2008; Zwart, 2017), the educational and organisational transformation process under WP5 can be modelled as follows:

- Input: Existing educational infrastructure, Industry 5.0-related skill demands, current workforce profiles, and identified organisational challenges
- Process: Implementation of TLF 5.0 interventions and the associated evaluation procedures
- Output: Measurable outcomes such as upskilling, technological integration, and alignment with Industry 5.0 pillars
- Outcomes: Contributions to both job transformation and business transformation, including the definition of new practices and procedures
- Impact: Medium-term effects such as the broader adoption of Industry 5.0 practices across participating organisations and beyond

Achieving meaningful impact will require triangulating findings from WP5 with results from other Work Packages (e.g., WP4 on Key Performance Indicators) and from related European projects. This will enable a more comprehensive assessment of the effectiveness and scalability of the proposed interventions.

Key technology	Sustainability	Human Centricity	Resilience
Additive Manufacturing	Material and energy savings in the production of high-value products Lower energy intensity and waste avoidance in the manufacturing process More energy-efficient production process Transportation of more basic materials simplifies supply chains. (Ford & Despeisse, 2016)	Enhancing creativity though complex geometries: artefacts of more exotic geometry can be manufactured, paving the way for some additional applications that can enable the creativity	Customisation of grippers and/or jigs as per the required part geometry (Stavropoulos et al., 2022)
Artificial Intelligence	Analysing large-scale interconnected databases to develop joint actions aimed at preserving the environment, supporting understanding of climate change, and modelling its impacts and improvement of the health of ecosystems (Vinuesa et al., 2020) ; UN, n.d.))	AI can enhance frontline workers' problem-solving skills by providing decision-support tools, enabling faster resolution without escalation. (Brynjolfsson et la., 2024)	Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries. (UN (n.d.))
Robotics	Reduced rework and scrap because of improved process accuracy (Lin et al., 2021)	Reducing the human load related to ineffective motions like holding and idling. Eliminating multiple motions Minimise the idle time. (Lin et al., 2021)	Lead-time reduction (Lin et al., 2021)

Table 2: Examples of technologies that could be adopted in the template matrix.

3 Methodology.

3.1 General approach and operationalisation.

As the entirety of WP5 involves developing and testing interventions within companies, it must be acknowledged that the core challenge lies in the nature of I5.0: (a) it is inherently complex, and (b) it remains largely unexplored in practical company settings. Therefore, all interventions must simultaneously address the three I5.0 pillars (human-centricity, sustainability, and resilience), while also considering: (i) job characteristics, and (ii) the broader company ecosystem.

The target audiences of BRIDGES 5.0 include managers, engineers, employees, technicians, industry workers, job seekers, and students. WP5 primarily focuses on managers and employees, while job seekers and students are the main focus of WP6. From an employee perspective, addressing all three I5.0 pillars requires an integrated and synergistic elaboration of current skills frameworks.

To support this effort, a structured documentation of specific requirements is proposed, building on the general directions presented in Deliverable D1.1. Competences and organisational issues are considered through the lens of socio-technical systems design. This intervention may also be seen as a company transition, aligned with the principles outlined in Annex 5 of D1.1. Accordingly, the TLF design will include the identification of associated practices to ensure the interventions are future proof.

The framework is deliberately agile and adaptable, accommodating future needs. For example, the “skills” attribute in the template may later be replaced with terms such as “personal capabilities” or “competencies,” thereby transforming the template into a meta-framework – both resilient and dynamic.

The intervention design process follows these phases:

- Pilot specifications including.
    - Technical needs
    - Three pillars integration
    - Company workflows
- Training design including.
    - Business transition requirements (i.e. integration of additional technologies)
    - Evaluation specifics
- Implementation of the pilots
    - The definition of the stages of the pilots (i.e. sessions for the defined TF)
- Evaluation and conclusion extraction
    - This will allow the extraction of conclusions on the success of the interventions, based on the aforementioned objectives.
- Generalisation and Feasibility Check
    - Evaluation of intervention feasibility and identification of features that enabled success.
    - Coordination with other WPs, such as WP4
- Making the interventions future-proof
    - Enhancement of the framework to support long-term applicability and sustainability

The final three phases are iterative and support continuous refinement of the integration of I5.0 features. Key Performance Indicators (KPIs), complemented by qualitative data from questionnaires, will be employed, particularly where direct quantification is not feasible. The evaluation process will also support the development of taxonomies for skills, organisational practices, and technologies. Deliverable D6.1 will play a supporting role, reflecting the shared vision and objectives between WP5 and WP6.

3.2 Operationalisation.

The intervention strategy itself includes clearly defined objectives (e.g. upskilling, reskilling, technology adoption) as well as clearly identified target audiences. However, its goals extend well beyond technical skill development to include:

- Enhancing decision-making capacity
- Strengthening communication and collaboration
- Managing conflict effectively
- Promoting adaptability across departments

Digitalisation enables employees to convert opportunities into real business applications, encouraging innovation while reducing cognitive load (Xun et al., 2021).

In parallel, modern companies must also cultivate inclusive and diverse environments. This includes promoting equal opportunity regardless of gender, age, socio-economic background, nationality, religion, or sexual orientation. A workplace where all employees feel accepted, respected, and safe, improves motivation and performance, and has positive implications for technological integration.

Organisational development depends on sustained, systematic efforts to promote effectiveness, resolving operational problems, and achieving strategic goals. Change management strategies – including transparent communication, thorough preparation, and ongoing monitoring – are essential. Managers must also be prepared to lead cultural change by example.

While it may be early, we propose heuristic definitions for assessing I5.0 readiness:

- A company that has completed an intervention addressing all three I5.0 pillars may be termed “I5.0-ready.”
- A company that has begun integrating interventions and has over 50% of work processes aligned with at least two I5.0 pillars may be termed “I5.0-inline.”

These definitions are provisional and will evolve in collaboration with other WPs, particularly WP4.

While BRIDGES 5.0 primarily addresses training interventions, secondary objectives vary depending on the context. A preliminary taxonomy of intervention objectives is presented in Figure 7, categorising interventions by their aims (e.g. people-focused, company-driven, proof-of-concept). The template matrix supports all such typologies. In the case of BRIDGES 5.0, the primary drivers are upskilling, the introduction of I5.0 concepts, and digital/technological familiarisation.

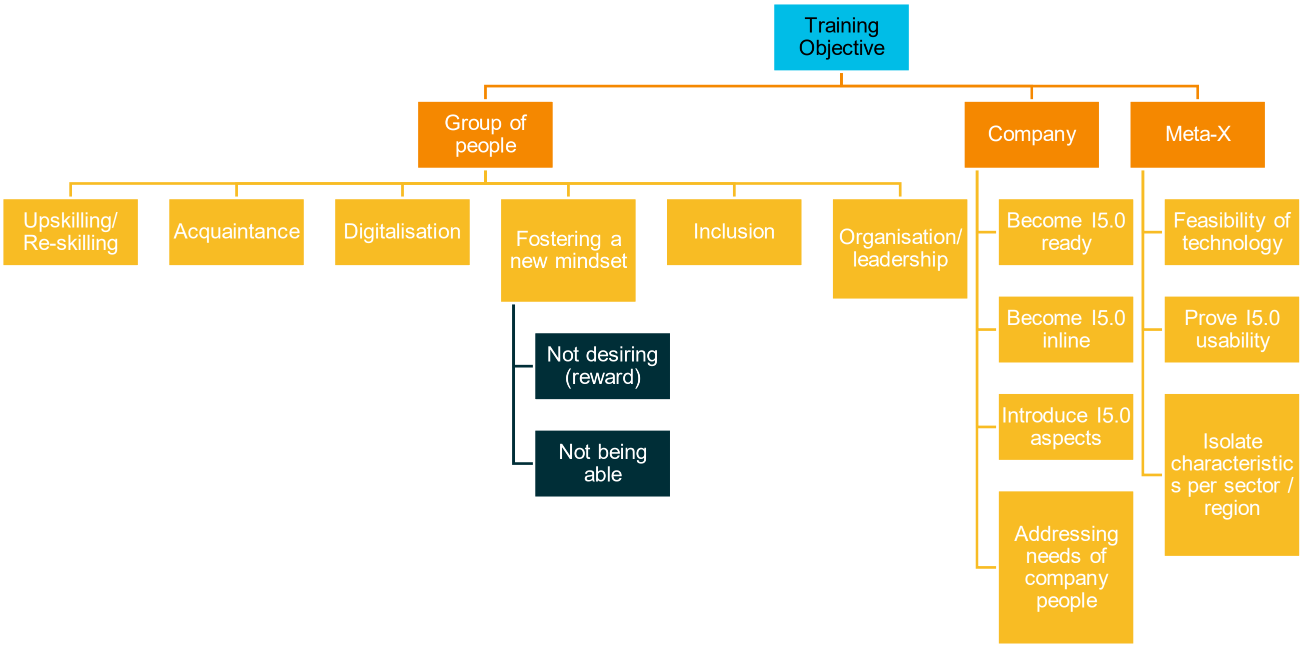

Figure 7: Tentative interventions taxonomy.

Bridges 5.0 is looking at the following interventions:

- Cooperative companies in Mondragon (Matz-Erreka and Fagor) share the same Industry 4.0 automation solutions: real-time and automatic process data collection and quality control systems.
- Infineon has created a new automation process, the Remote-Operations Control Centre (ROCC), which handles the 24/7 centralised place-handling exceptions in real time and in all aspects, addressing the needs of a new automated line.
- Kitron UAB and HybridLab are two companies cooperating in the field of Kitron UAB employee training. Kitron UAB has automation and robotics in its battery production lines. The company boasts a high level of specialist expertise in technology and industrialisation; however, the departure of many highly qualified employees has created a challenge in meeting production goals. HybridLab is an educational company providing hybrid learning and teaching methods. The company offers innovative peer-to-peer simulation training programmes.
- Comau has automation and robotics in its production lines, and it also has a very advanced training system. Its Academy offers trainings and courses that cover a wide range of topics, from elementary schools to universities, and from post-diploma to workers/unemployed people who need upskilling.

3.3What are we measuring?

According to Annexe 1, there are two perspectives from which interventions and I5.0 in general can be evaluated: (1) Company-level perspective: Focused on organisational practices; (2) Job-level perspective: Centred on human experience and roles. In line with this, WP5 adopts the "relative" approach outlined in Annexe 1, applying a differential assessment method. This involves comparison of job and company conditions before and after the intervention, at two defined time points (T1 and T2), visualised in Figure 8 along a vertical time axis (points A1 and A2).

On the job side, measurements will assess the intervention's effect on key criteria (e.g. upskilling). This enables comparative evaluation across interventions. Meanwhile, the company side will be assessed in terms of business transition, using heuristic metrics in the absence of a standard. Both perspectives will inform the identification of best practices and potential metrics, in close collaboration with WP4.

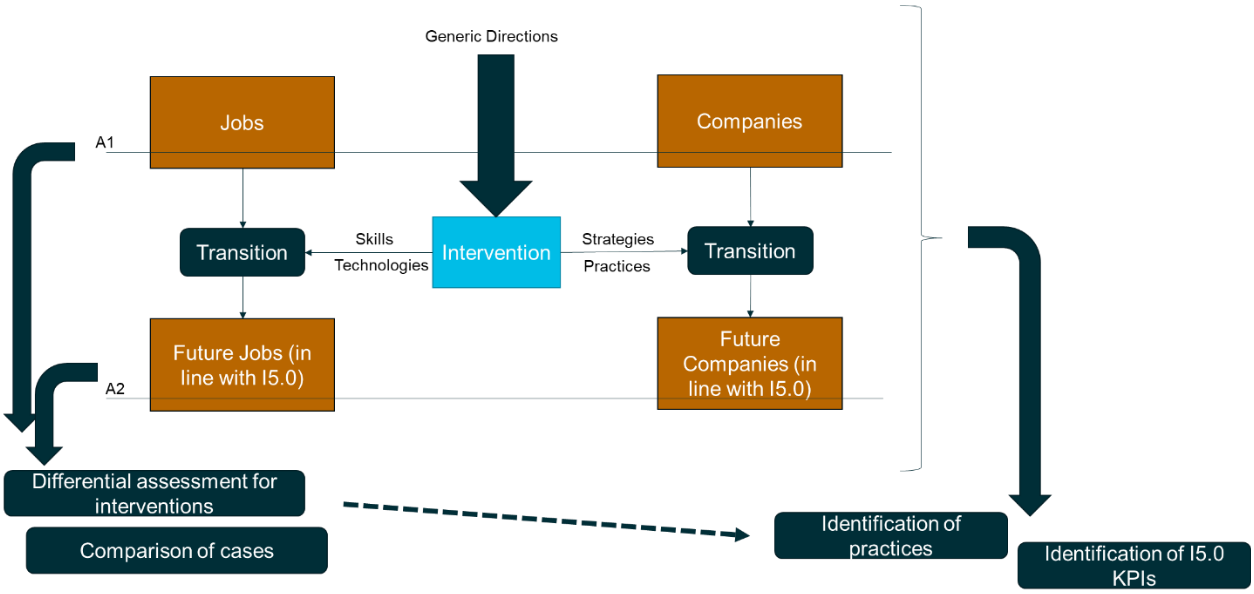

Figure 8: Methodology for measurements, conclusions extraction and generalisation.

3.3.1 The success definition.

Three aspects have been considered for studying the success of Industry 5.0 integration in training, as shown in the Figure:

- **Upskilling** is assessed through a pre- and post-intervention comparison using a Likert scale. An increase in the average scores on relevant questionnaire items is considered sufficient evidence of upskilling.
    - An indicative upskilling questionnaire is provided in Annex 4. However, the specific items have been tailored to the individual needs of each participating company.
    - The questionnaire items are organised according to thematic pillars.
    - As upskilling is treated as a statistical construct, reference thresholds have been applied using the concept of the *Minimally Important Difference* (MID). A numerical threshold of **0.5** is employed as the reference point for absolute changes in scores, based on Norman et al. (2003). This approach is complemented by an additional metric based on standardised effect size, specifically **Cohen's *d*** (Madsen, 2016; Vranic, 2013; Lakens, 2013).
- **Company-level effects** are also measured using differential analysis, based on the corresponding questionnaire outlined in Annex 4.
    - To assess impact, the distribution of company-level indicators is examined, and the observed change is compared to the **first quartile** of the baseline distribution. This method approximates a distribution-based interpretation of the *Minimally Important Difference* (MID), in line with Revicki et al. (2008).

- **The intervention itself** is evaluated qualitatively using a Likert-scale-based questionnaire administered to company representatives, focusing on the perceived ease of implementation. An average score above **3.5** on relevant items is heuristically interpreted as agreement with the statements, and thus, as a positive evaluation of the intervention's feasibility.

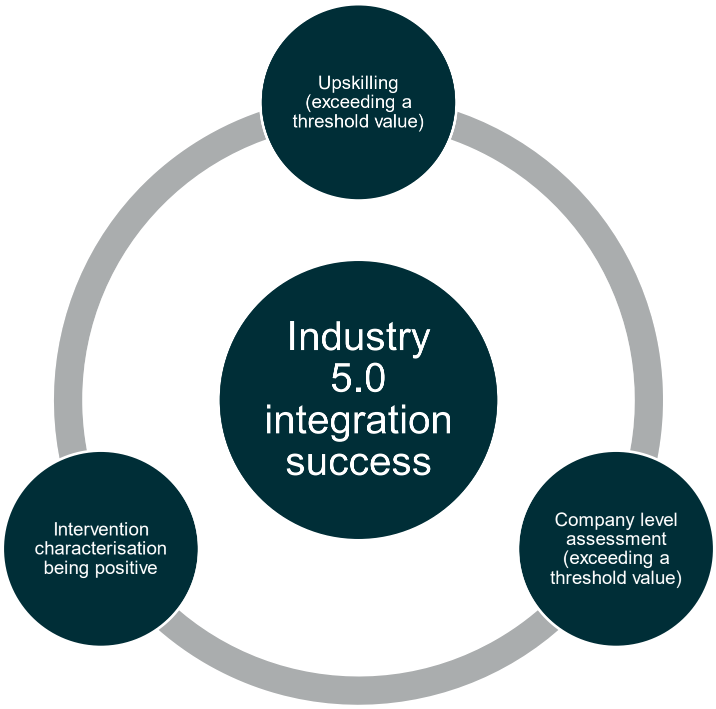

Figure 9: aspects affecting the success of the interventions.

In addition, a meta-analysis framework is adopted in order to study the effectiveness of the methods used in the interventions (namely TF and LF). This is elaborated in section 6.3.

3.3.2 Competences extraction.

To identify emerging Industry 5.0 competences, a structured, data-driven methodology is applied across participating companies. For each company, the survey responses related to upskilling served as the foundational dataset.

Subsequently, Principal Component Analysis (PCA) was performed individually on each company's dataset (The Jamovi project, 2022; R Core Team, 2021; Fox et al, 2020; Revelle, 2019). This statistical technique enabled the reduction of the data dimensionality and facilitated the identification of latent structures within the questionnaire responses. These latent structures, reflected as principal components, were interpreted as indicative of distinct, underlying competences.

Following the PCA, each component grouping was subject to qualitative interpretation to hypothesize which emerging competence it might represent. To support this interpretative process, a large language model (LLM) (OpenAI, 2024) was employed to generate initial semantic label for each component. These preliminary labels were then critically reviewed to ensure validity, contextual alignment, and clarity.

The resulting set of interpreted components, validated through both statistical and semantic analysis, is presented in the following section as emerging competences.

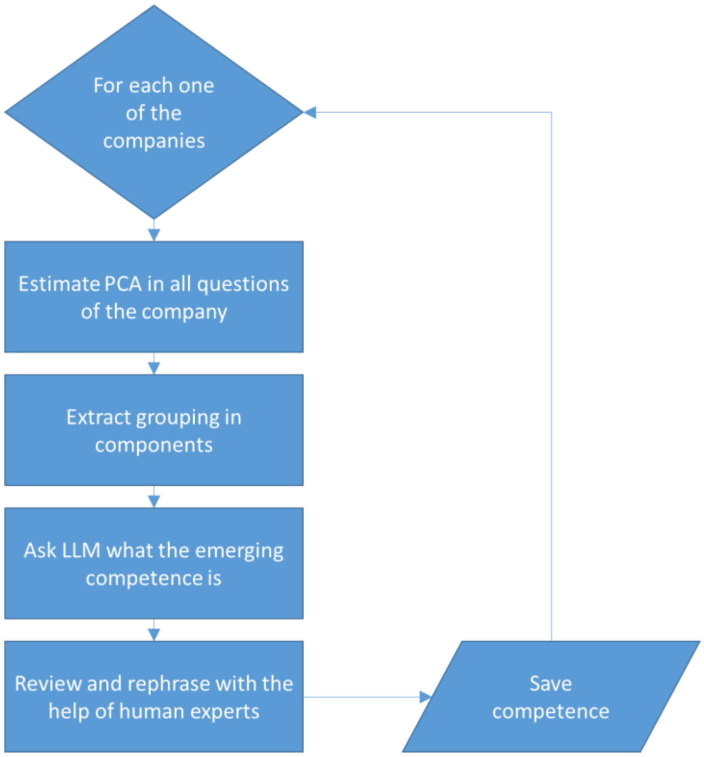

Figure 10: Methodology for extracting competences.

3.4 A phased approach to the pilots.

The methodological structure of the project aims to deliver a customised training system addressing all three I5.0 pillars. The six implementation phases, distributed across the four WP5 tasks and T6.4, are outlined as follows (see Figure 11):

- Phase 1 – Specification: Based on company needs, a specific problem[3] is defined to anchor the training intervention. This provides motivation for the company and a foundation for experiential learning. Specifications are gathered using the template matrix.
- Phase 2 – Design: A TLF structure is developed, building on existing training systems (if applicable), expert input, and company-specific needs. The framework should be adaptable, responsive to both company and trainee requirements, and designed using the Annex 3 template.
- Phase 3 – Implementation: The designed TLF is deployed as per specifications.
- Phase 4 – Evaluation of the TLF and Feasibility check: The pilots are assessed, facilitating conclusion-drawing and practice identification.
- Phase 5 – Futureproofing: Structural adaptations to training interventions are proposed. Conclusions for wider and future application are drawn from post-intervention analysis and stakeholder dialogue (companies and WP leaders). This will be documented in D6.3.

[3] for the TF procedure. For the LF, there is a technology involved.

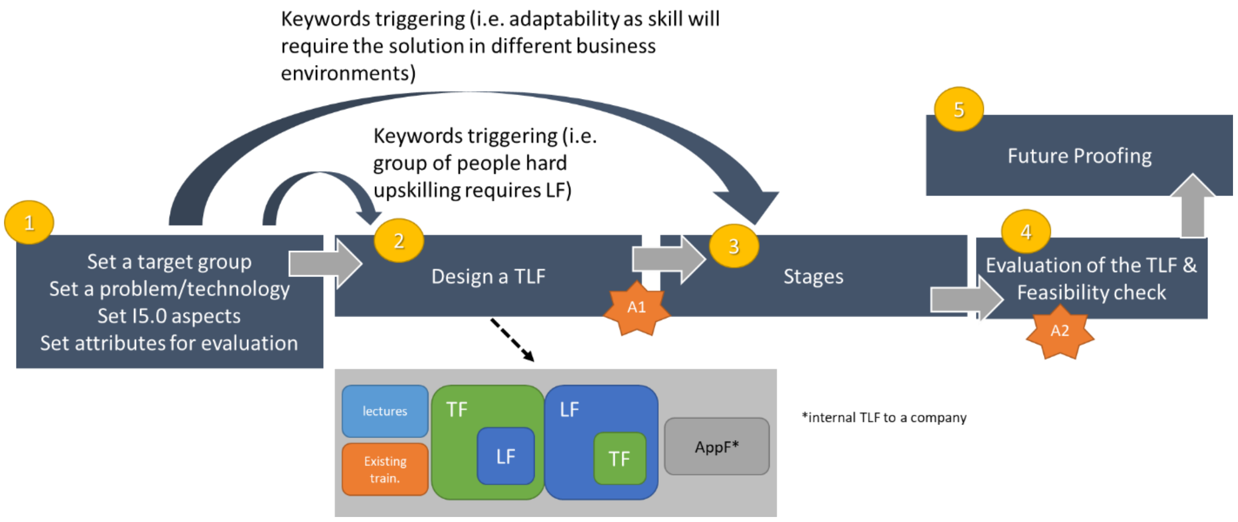

Figure 11: The phases of WP5 implementation.

Information flow across phases is essential. Keywords such as "co-creation" can trigger changes in structure or content. In its most general form, the TLF will include a combination of Teaching Factories (TFs), Learning Factories (LFs), existing training systems, lectures, gamification, and Application Factory[4] elements. Future implementations may involve generalised TFs addressing internal communication challenges between departments such as HR, operations, and design.

The concept of workplace innovation (Carranza et al., 2020; Oeij et al., 2023b) underpins these interventions.

[4] It is defined as a TF within the company itself

4 Phases 1 and 2 - Specifying and designing the training pilots.

4.1 Introduction.

This section outlines the specifications and pilot designs for the four case studies included in the project. It is important to note that these case studies are highly diverse, each with distinct starting conditions and contextual factors. In section 4.7, four companies are added that undertake 'partial interventions' with the specific aim of 'introducing selected aspects of Industry 5.0.' These cases are not described separately at this stage but will be reported comprehensively upon completion of the implementation phase.

The duration and structure of the pilots align with the framework presented in Section 2. However, the terminology and descriptions used in this section have been enriched to reflect the specific 'language, practices, and needs of the participating companies.

4.2 Pilot 1 - Mondragon Corporation: from Industry 4.0 to Industry 5.0.

4.2.1 Summary.

Target audience:

- **Company workers**
- **Managers**

Involved organisations:

- **Matz-Erreka, S. Coop.**
- **Fagor**
- **Mondragon University, S. Coop.**

Several cooperative companies in Mondragón have implemented Industry 4.0 solutions to enhance the productivity of their processes, including automatic real-time data collection systems and/or automated quality control systems. After implementing these technologies, several companies encountered similar challenges in maximising the benefits of the new technology. The primary challenge is related to the involvement of workers in utilising the technology. All these technologies involve empowering people through a process. However, this empowerment process does not occur once the technology is in place. An I5.0 training solution is needed not only to address the usual skill gaps of workers but also to address the skill gaps of managers related to the managerial/organisational changes that must accompany the implementation of new technology. This solution will need to make the empowerment of workers a reality, enabling them to leverage the new technology fully.

4.2.2 Background and contextualisation of the intervention.

Many cooperative companies in Mondragon have been working on Industry 4.0 improvements over the past years. The primary objective of Industry 4.0 automation is to enhance process productivity. One of the most common Industry 4.0 improvements has been the implementation of real-time automated data collection and monitoring of key process parameters to enhance efficiency and responsiveness to unexpected events that disrupt process productivity on a daily basis. Another Industry 4.0 improvement has been the implementation of automatic quality control systems, utilising visual control systems to inspect 100% of the manufactured parts.

Both improvements in automated systems have become very common in Mondragon companies. Although the pilot study will focus on two of them (Matz-Erreka and Fagor Ederlan), the results of the pilot study will be of interest for the rest of the Mondragon companies. Both automated systems require a change in the way people operate and work in the process. This change is related to a more empowered role within the company. Empowerment is understood as taking care of the automation systems and making decisions to improve the process as unexpected events arise on a day-to-day basis. That is, they require an attitudinal and behavioural change in people if the company wants to get the best out of the implemented automation. However, most companies implementing these technologies face difficulties in leveraging them, primarily due to the required attitudinal and behavioural changes in their workforce. People do not instantly adopt these new technologies, and therefore, the company is not fully leveraging them.

The training course selected to pilot this intervention is “*Workplace improvement to foster attitudinal and behavioural changes in order to take advantage of the implemented automation*.” The pilot was held in two companies: Matz-Erreka, S. Coop. and Fagor Ederlan, S. Coop.

- **Matz-Erreka** (https://www.erreka.com/): The headquarters of this company are in Antzuola (Gipuzkoa, Spain). They are a manufacturing company that manufactures technical plastic injection moulds. They manufacture (using plastic injection processes) a wide range of parts for applications in different sectors such as automotive and bio-health. They have a large fleet of injection moulding machines from 15 Tn to 400 Tn. They manufacture in six plants around the world: Spain, Mexico, Czech Republic, and China, employing 500 people.
- **Fagor Ederlan** (https://www.fagorederlan.com/es/): the headquarters of this company are located Aretxabaleta (Gipuzkoa, Spain). They are a manufacturing company of Chassis and Powertrain components for the Automotive sector. They operate 17 manufacturing plants worldwide, located in Spain, Mexico, Brazil, Slovakia, and China. They employ approximately 3500 people.

4.2.3 The challenges.

Both companies in this pilot share a similar Industry 4.0 foundation, specifically in the deployment of real-time automated process data collection and quality control systems. These technologies inherently necessitate and support the empowerment of shop-floor workers, as their effective use depends on workers’ ability to interpret data, respond autonomously, and contribute to improved productivity and resilience.

However, both companies face a shared challenge: how to design the workplace in a way that empowers employees to utilise this technology and fully leverage its potential actively. In practice, the existence of automation alone does not guarantee its effective use; instead, it requires a corresponding transformation in workplace design and management practices.

In response to this, BRIDGES 5.0 has set out to develop the necessary capabilities for employees to internalise technology and make it “their own”. In this context, “capacity development” primarily involves upskilling and/or reskilling managers and technicians, rather than frontline workers. The focus is on enabling managers to understand the underlying reasons why employees may not embrace the autonomy and empowerment made possible by automation, despite, in some cases, being co-owners of the companies.

This requires managers to develop new capabilities in organisational design and change management – specifically, how to implement automation in ways that foster rather than inhibit worker autonomy. This includes the ability to reshape or innovate workplace environments so that employees are genuinely empowered to use, maintain, and make decisions related to technological systems. Such empowerment, in turn, is essential to achieving improvements in process efficiency, adaptability, and responsiveness.

Ultimately, we posit that the 'core challenge in this pilot lies at the managerial level', rather than the employee level. It is managerial understanding, strategy, and action that will determine whether technological empowerment is realised in practice.

4.2.4 Intervention: the methodology for the pilot study.

The first phase of the pilot study will follow the generic scheme, contributing then to generalisation: (i) gather learnings and conclusions from past experiences of several companies, (ii) design a "training 5.0 solution", (iii) test the solution in Matz-Erreka and Fagor Ederlan, (iv) evaluate its impact. Figure 12 illustrates this process. The figure shows that several companies are implementing the same automation (see the left-hand side of the figure with "company 1", "company 2", etc.). So, one of the tasks of this pilot study is to understand how they have implemented this automation and the difficulties (or not) they are facing. This will enable us to gain important insights into how companies operate/implement these automation processes, as well as how people react to them. The result of the analysis will be "learnings and conclusions" as an important input for the design of the I5.0 training solution.

The second phase of the pilot study is to design the I5.0 training. It is expected that the training will primarily target the company's managers. The I5.0 training solution will need to contribute to the managerial skills required to design and manage a working environment that fosters the empowerment of people. These technologies require a new role for people, empowering them to make decisions (using the technology) as quickly as possible to achieve process productivity and resilience. It is expected that the managerial knowledge required to improve the workplace (in order to foster the empowerment of workers) will be similar in both cases (since management principles are very similar for different companies). It is important to stress that the training intervention will primarily focus on managers and technicians training since the learnings and conclusions gathered from Mondragon companies show that the challenge we are facing is not a lack of skill challenge (from the worker side) but more a lack of consciousness about how to implement these automations and design the resulting new job so that an organisational context is developed that invites people to embrace the new technology (job).

The third phase will be to test the I5.0 training solution in both companies (Matz-Erreka and Fagor Ederlan). This testing process will involve managers as participants in the training sessions. Finally, the fourth phase will evaluate the training solution. This evaluation will likely result in revisions and improvements to the I5.0 training solution.

Figure 12: MONDRAGON cases: methodology.

Table 3 lists the main directions of the intervention in bold to develop I5.0 workforce skills. The pilot study contributes mainly to the “Human-centric” and “Resilient” parts of the matrix. Sustainability will presumably be improved because of the improvement of human centricity and resilience.

It is important to point out that the Teaching Factory intervention is aimed at the managerial level. However, intervening at the managerial level should imply a change in mentality of both the management (since they are taking part in the training sessions) but also at the worker level (since they are the ones who should feel the changes at the management level).

	Creating Industry 5.0	Skills for in Industry 5.0
General	Design and use digital technologies and AI systems in a way that meets Industry 5.0's three objectives	• Learn and work with digital technologies. • Learn new digital technologies. • Understand the basics of complex digital technologies and AI systems.
Human-centric	• **Understand human centricity (MANAGERS)** • **Support and implement worker participation in decision-making processes (MANAGERS)** • **Give control to the shop floor (MANAGERS)** • Use shared control between humans and machines. • Use human-centred design methods. • Use assistive/supporting/augmenting technologies	• **Show responsibility, intrapreneurship (WORKERS)** • **Make use of being empowered (WORKERS)** • **Participate in processes related to (re)design/change (WORKERS)** • Act inclusively. • **Empower through load reduction/ decision making /.. (MANAGERS)** • **Be able to communicate in participation processes (Internal & external interaction) (WORKERS AND MANAGERS)**
Resilient	• Assess the company's dependencies through planning for different scenarios and risk assessments. • **Develop a resilient production process.** • Develop a resilient network of suppliers, partners, and customers (systemic thinking) / supply chain/value chain. **Encourage creativity, innovation, and flexibility/self-organisation**	• **Understand/integrate resilience.** • Understand company policies. • **Engage in lifelong learning.** • **Develop ability to adapt.** • Develop creativity. • **Enable self-organisation; manage yourself**
Sustainable	• **Care for the environment.** • Conduct environmental impact assessments. • Conduct lifecycle assessments. • Make and promote 'green choices'	• **Care for the environment.** • Act sustainably • Understand circularity. • Conduct lifecycle assessments

Table 3: MONDRAGON: main I5.0 directions addressed in the intervention.

4.2.5 Overall framework for Mondragon.

The intervention is based on a generic procedure involving two distinct organisational scenarios, each requiring a different approach. These scenarios are differentiated by managerial attitudes toward employees and the role of human-centred practices in the adoption of automation.

Rather than two separate implementations, these complementary scenarios are used as components of a diagnostic and design framework. The framework helps assess a company's current state and define the most relevant training needs. Depending on the company's situation, Scenario 2 may be used directly, or the organisation may progress through both scenarios over time. The overall goal is to support a shift toward the more advanced, human-centric model represented by Scenario 2.

Scenario 1: Traditional Management Approach

In the first scenario, managers predominantly adopt a traditional view of management, treating workers primarily as resources to be managed. This perspective often results in the underutilisation of employee autonomy and a missed opportunity for engagement with technological change. Key indicators of this scenario include:

1. Performance-driven automation: The primary motivation for automation is productivity, often accompanied by attempts to reduce the perceived importance of the human role in manufacturing.
2. Top-down implementation: Automation initiatives are introduced hierarchically, without meaningful worker input.
3. Job devaluation: The redesigned roles result in reduced complexity or significance, diminishing workers' sense of purpose or influence.

In this context, the intervention aims to raise awareness and develop critical thinking among managers and technicians about how organisational structures and management beliefs shape employee behaviour, and how this behaviour, in turn, affects outcomes such as performance, motivation, and absenteeism.

The learning outcomes for Scenario 1 include:

1. Understanding the "mirroring effect": Recognising how manager and worker behaviours reflect and reinforce one another.
2. Recognising organisational influences on collective behaviour: Identifying how job design, company size, technological setup, and managerial roles affect group dynamics.
3. Understanding culture-behaviour cycles: Exploring how organisational culture shapes collective behaviour and how that behaviour reinforces underlying cultural beliefs.
4. Analysing organisational belief systems: Unpacking how core assumptions drive practices, and how these practices shape and reinforce behavioural norms.

Scenario 2: Human-Centric Management Approach

In contrast, the second scenario involves managers who regard workers as individuals with human needs and who actively seek to harness those needs as a source of competitive advantage. In this scenario, the intervention aims not only to promote awareness but also to support organisational change and the design of empowering, human-centred workplaces.

Key indicators of this scenario include:

1. Dual-purpose automation: Technology adoption is motivated by both performance and worker well-being.
2. Hybrid implementation approach: A combination of top-down strategic direction and bottom-up engagement with employees.
3. Job enrichment: Work is redesigned to remain meaningful, complex, and reliant on human contribution.

Here, the intervention builds on the same foundational learning outcomes as in Scenario 1 but extends to more profound organisational transformation. The complete set of learning outcomes includes:

1. Understanding the "mirroring effect" between worker and managerial behaviours.
2. Recognising the organisational practices that shape collective behaviour (e.g. size, technology, job design, leadership structures).
3. Understanding the role of organisational culture in shaping and reinforcing behaviour.
4. Exploring how underlying organisational beliefs shape practices, and how these practices influence and stabilise behaviour.

5. Defining what constitutes a human-centric organisation, including practices aligned with fundamental human needs.
6. Learning how to implement human-centric practices that enable employees to adopt new technologies and feel genuinely empowered in their roles.

The previous contacts made with the two companies (Fagor Ederlan and Matz-Erreka) showed that the challenge does not rely so much on worker up- or re-skilling, but rather on the attitudes of the worker. Skills training is not the challenge.

The trainers are university researchers and consultancy experts.

The profile of the trainees is mixed:

- Manager trainees are mostly business management graduates.
- Technician trainees are engineers (IT, mechanical and electrical engineers).

4.2.6 Identification of any additional practices that can be integrated.

The design of the training has been co-created with the management of both companies (Fagor Ederlan and Matz-Erreka). During the early stages of the training design process, managers were actively invited to contribute by commenting on, modifying, or adding elements they considered relevant to their specific organisational context. Several suggestions were incorporated, particularly those relating to the timing of the sessions and the emphasis placed on specific topics that managers identified as priorities.

4.2.7 Description of the main Industry 5.0 aspects covered by the intervention.

The following matrix shows the different aspects of I5.0 covered in this pilot study. All the concepts specified in Table 4 have been applied to both companies: Matz-Erreka and Fagor Ederlan, since the implemented automation and challenges are the same in both companies.

	(a) Human	(b) Resilience	(c) Sustainability	(d) Social
A1 Skills	Decision making and cognitive load reduction. [soft skill- workers] Culture and change management [soft skill - managers]	Networked automation [hard skill]	Ability to use of A2 Technologies hereafter [hard skill]	
A2 Technologies	AI	AI	Resources Efficiency	
A3 Tasks				
B KPIs	Load reduction Human autonomy	Process flexibility (fast decision making) Integration of different workflows (related to networked automation)	Process Productivity Integration of different workflows (related to green technologies)	
C Strategies	Process of automation (How)			
D Organisation	Managerial role to make the empowerment of people a reality			Support digitalisation in SME's ecosystem

Table 4: MONDRAGON: main I5.0 aspects covered by the intervention.

4.2.7.1 Preparation of the training pilot.

The preparation relates to the learning material and the delivery mechanism. The material was developed before the summer. Specifically, the following material is relevant:

1. The "mirroring effect" exercise.
2. Material for the critical thinking.

The timeline is:

From	April 24	To	Sept 24

No new equipment was required, as the intervention was more conceptual than technological. Additionally, the trainers were selected, mainly coming from the Mondragon Goi Eskola Politeknikoa.

4.2.7.2 Training pilot description.

For the companies that meet the *scenario 1* criteria, the design of the intervention (that is aiming to raise awareness at the managerial level) will be the following:

Step 1 (Course): Raising Awareness of Collective Behaviour (2 hrs). This step aims to collaborate with managers to understand that an important part of collective behaviour (for example, whether they embrace or reject new technology) is influenced by managerial issues and organisational practices.

- Representation of the “mirror”. This exercise is to work on the systemic perspective of worker behaviour.

Step 2 (Teaching Factory): Developing Critical Thinking of Managers (8 hrs). This part of the intervention aims to develop awareness of how beliefs (organisational, collective) condition organisational practices, which, in turn, condition collective behaviours.

- Identifying organisational practices. What are the organisational practices that are in place?
- Identification of underlying beliefs. Why? Why are these organisational practices in place? What are the underlying beliefs? This part of the intervention aims to raise awareness of the beliefs that guide management and therefore condition behaviour (in this context, the adoption of technology and of the new empowered role).

For the companies that meet the *scenario 2* criteria, the design of the intervention aims to work with managers on organisational practices that align with the human-centric logic. The aim is to collaborate with managers on potential future changes in the organisation to improve the adoption of the new technology and the new empowered role.

Step 1 (Course): Raising Awareness of Collective Behaviour (2 hrs). This is the same exercise as described above.

Step 2 (Course): Developing critical thinking of managers (4 hrs). This is the same as described above, but with a shorter version, as managers will be aware of many of its reflections in this scenario.

Step 3 (Teaching Factory): Developing Human-Centred Organisational Contexts (8 hrs). This part of the intervention aims to address specific organisational practices that align with the logic of human-centredness.

4.3 Pilot 2 - Infineon: Remote Operations Control Centre (ROCC).

4.3.1 Abstract.

Since several I5.0 themes are considered within this pilot, the intervention is designed to include two lectures, one technical and one related to soft skills, as well as a TF that has two distinct steps (constituents). The *first step* of the foreseen TF will be the primary focus within BRIDGES 5.0 and it will encompass all knowledge related to the change in operating setup, including knowledge of the room and its operation, entire factory logistics phases for interdependent areas, and empowerment of the workforce within the new workplace context. At the end of this step, the primary expected outcome will be comprehensive knowledge of factory performance for efficient decision-making.

The *second step* of the TF will focus on introducing AI for logistics management and decision-making, to be run through a simulation environment (e.g., Tool Downtime Events logbook). Given the nature and type of this second step, it should be considered an 'if/when applicable' scenario.

The main target groups of the intervention are the *Line experts* (physically present in the ROCC), their Team leads, and the representative of *Production Management*.

Target audience:

- **Line expert**
- **Team leads.**
- **Production Management**

4.3.2 Background. Contextualisation of the intervention.

In one of the manufacturing sites of Infineon (Villach, Austria), products of different sizes are manufactured in a production line organised into eight process departments. To increase the level of mass production, it has been decided to expand automation and modify the operations setup for a specific type of tool set, while keeping the others unchanged.

The “heart” of this change is the **R**emote-Operations Control **C**entre (ROCC), a 24/7 centralised location that handles exceptions in real-time across all aspects. In concrete terms, the ROCC is responsible for:

- Logistics decisions of all specific areas in one centralised place outside of the production environment (remote)
- Reacting effectively/timely to machine downtime, considering overall factory performance indicators.

The room features twelve innovative workplaces equipped with top-level ergonomic solutions to ensure optimal comfort throughout its 24/7 operational functioning. The alarm deployment system and Multi-Consoling setup (all signals are mixed into this room independently of the rest of the facility, meaning ROCC is not affected by anything happening outside of this room) complete the organisation.

Given the interdependencies existing at the factory level, the change in setup concerns not only the workforce directly involved in the ROCC (approximately 50 people) but also around 1,200 people in total.

4.3.3 Situation to change.

4.3.3.1 Overview.

The change of operational setup, in terms of jobs within the company, is explained in the image below:

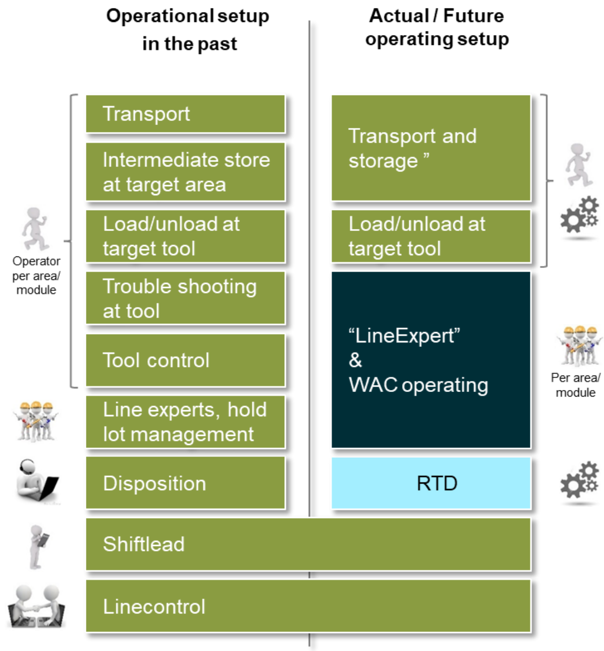

Figure 13: INFINEON: transition in occupations.

The change in operational setup was initiated only recently and, therefore, is relatively new in its implementation. The most critical aspects to first clarify are:

- Only some activities previously performed by an operator have been automated without the replacement of personnel that has been upskilled/reskilled to perform the role (e.g. job upskilling from Operations, Unit Process Engineering and Maintenance).
- Only one type of tool set is affected by this change, which has originated from an increasing need for mass production through higher automation. The others still run with the previous setup.

The Line Expert, identified by the blue square in the image, is empowered to sit in the ROCC. A Line Expert is the role of an expert in a process department like Lithography, Furnace, or Implantation. By using the **W**ork **A**rea **C**ontrol software (a software for entry point monitoring, where issues occur and acts as a fast decision point for logistics decisions), some tasks previously performed in a separate manner have now been centralised (namely, Troubleshooting at the tool, Tool control, and *Hold lot management*).

Figure 14: INFINEON: ROCC.

The logical disposition between the process steps is performed through the Real-Time **D**ispatcher. Based on data coming from different sources, a rule-set configuration is used to define what is to be done next in the process from a logistic point of view, based on capacity of the production line that is shared over all the products and based on planning for each division (Automotive, Industrial Power Control, Power & Sensor Systems, and Connected Secure Systems). In the previous setup, a higher level of human interaction was needed to perform the dispositions.

4.3.3.2 Status before the intervention

Technical description of the case

There is a set of skills (both soft and hard) that are deemed necessary for the proper management of key parameters in relevant areas for the whole factory production. This is in addition to already existing knowledge for the assigned area. The skills can be grouped as follows:

- Logistics management of the process area.
- Decision-making for particular topics relevant to a specific area, including overall production connections.
- Responsibility for the communication interface to the functional lead department (Line control), to the other seven process areas and to the internal department responsible.

Previous Status of Training within Infineon Technologies Austria

Currently, there are five process areas in pilot/early-stage mode. Additional areas are under development and are expected to be deployed by the end of the year. The most relevant aspects to be considered are mainly related to:

- Change of working environment responsibilities/tasks/interfaces.
- Ensuring and implementing the new communication and organisational dependencies in 24/7 working mode.
- About 50 direct affected individuals; ~1200 indirectly affected at different levels.

At present, training is divided into:

- Basic training: this is a training matrix composed of elements of Logistics, Performance and Data analysis, and process specifics of each department. This training is provided as part of the starting guidelines.

- Soft skills training: Based on planned changes, it focuses on empowering people and decision-making. This is provided by the process area leads and the functional lead department.

4.3.3.3 Objectives for the intervention.

The objective is to, considering the targets group listed above, integrate in their work and behaviour the three pillars of **Human Centricity**, **Resilience**, and Sustainability. These pillars have been operationalised as:

Human-centricity:

- Ergonomic working environment.
- Semi-automated alarm trigger.

Sustainability:

- Resource efficiency.
- Idle times reduction.
- Ensures a future scalability organisation setup (reduced footprint).

Resilience:

- Focus on direct communication by reducing unnecessary information exchange (forcing the need-to-know principle).
- Operators are given the capability to react effectively/a timely manner to machine downtime.

Given the specific nature of the intervention, an additional set of extra targets has been detected:

- Additional soft-skills training.
- Decision making.
- Personal improvement.
- Empowerment in the organisation.
- Analytical skills to interpret and consider big data.
- Management of cross-over areas to overcome department borders.

4.3.4 Intervention.

4.3.4.1 Which intervention?

The intervention focuses on modifying the operational setup to incorporate higher automation and multiple data-driven decision-making processes. The training includes two classes that are described in section 4.3.5, hereafter. It also includes a TF session, focusing on solving a problem, namely that of organizing data towards decision making, which is being implemented in two consecutive steps, with the second step contingent upon the availability of time and resources.

The *first step* of the intervention focuses on organisational and operational setup changes, involving knowledge transfer to enable an efficient decision-making process. The **background** comes from the fact that there are now many separate and partially unfiltered inputs for decision-making (different data sources, applications, time stamps, etc.). In this case, the recognised **problem** is that the ROCC workforce is not used to working with the system-provided decision proposals, compared to the previous setting. The **potential solution** to this need involves specific training activities that empower and facilitate the acceptance of change, thereby enhancing work performance within the new environment.

The key aspect lies in the “new approach” of dealing with data coming from different factory areas. In the previous setting, each person was responsible for a specific area, and therefore, each worker was “trapped in his silo.” In the new setting, the person is trained in a decision-making process that is equivalent across different areas, enabling the human resource to work in various places (in a long-term scenario, cross-boarding enablement might also be applied geographically).

Equally important is adjusting the communication interface to accommodate changes in responsibility, resulting in a more streamlined decision-making process. An emblematic case is the maintenance of tools, which is now based on a complete factory overview: it is possible to say which tool is more important than others in the factory (*Prioritisation of maintenance*) and act, accordingly, depending on the resources of the process department. In the past, when a tool was down, a support request would be made to the shift lead without knowing the importance of that tool in the context of the entire production line.

Because of these reasons, at the end of this step, the main expected outcome will be *complete factory performance knowledge* for efficient decision-making.

The **target groups** of this training are Line experts, Team leads, and representatives of Production Management.

The *second step* of the intervention focuses on the technology that supports the decision-making process. The **technical background** refers to the relevant flow of data coming from highly automated production areas with different sources (time ranges and refreshing cycles, formats, points of view), lacking a proper aggregation with current applications not being able to provide context-based visualisation of information/knowledge like time, role, topic, priority (**problem**). The **potential solution** that has been identified is **Artificial Intelligence,** both for visualisation/UI architecture/system and data provision to ensure an improved decision basis.

The **target groups** for this training are line experts and team lead.

4.3.4.2 Taking company practices into account.

Some members of the group of workers (trainees) who will participate in the intervention were involved in the co-creation of the design phase. During a brainstorming session, the project's status was presented, and the requirements for designing the Teaching Factory were explained.

During the brainstorming session, every participant identified 1 or 2 topics for the training courses, keeping in mind the objective of acquiring comprehensive knowledge of factory performance for an efficient decision-making process, regardless of the process.

After asking the trainees about their preferences for the desired content of such a training intervention, *Logistics KPIs* and *Communication interface* were the most preferred fields. Regarding logistics, a consensus has been reached on adopting the principles of “Factory Physics” as the framework for logistics operations and potential improvements. About Communications, “conflict resolution” and “effective communications techniques” have emerged as favourite elements to be envisioned.

The structured collection of feedback eventually led to its inclusion in the design template.

4.3.4.3 Expected long-term organisational/systemic changes.

The following changes are desired:

- Empowerment of ROCC personnel thanks to acceptance/understanding of the change and systemic training.
- Highly efficient decision-making process.
- Case-based semi-automated decision workflow in the production system.
- Cross-over factory-relevant decision taking (with aligned module dependencies).
- Increasing communication efficiency.
- High availability of data and following transparency.
- Enablement of cross-over responsibilities,

4.3.4.4 Main Industry 5.0 aspects covered by the intervention.

The matrix shown below lists various aspects of I5.0 that will be covered within the listed intervention.

	(a) Human	(b) Resilience	(c) Sustainability	(d) Social
A1 Skills	Data interpretation			
A2 Technologies	Case-based semi-automated decision workflow in the production system	Self-build data interpretation interface		
A3 Tasks	Cross-over factory relevant decision taking (with aligned module dependencies)			Acceptance of decision through all interfaces made by line experts
B KPIs	Increasing communication efficiency, needed resources for logistic decision compared to the production´s capacity, high attention of work force	High availability of data and following transparency	Resource efficiency Idle times reduction	
C Strategies		Substitutions/Fluctuations of people in case of need		Enable cross-over responsibilities
D Organization				Better functional organization for future capacity extensions

Figure 15: INFINEON: Main I5.0 aspects covered by the intervention.

Table 5 reports the main directions adopted in the intervention to develop I5.0 workforce skills (from D1.1).

	Creating Industry 5.0	Skills for in Industry 5.0
General	Design and use digital technologies and AI systems in a way that meets Industry 5.0's three objectives	Work with digital technologies. Learn new digital technologies. Understand the basics of complex digital technologies and AI systems
Human-centric	Support and implementation of worker participation in decision-making processes Use shared control between humans and machines. Use assistive technologies	Make use of being empowered. Act inclusively. Empower through load reduction/ decision making. Be able to communicate in participation processes (Internal interaction)
Resilient	Develop a resilient production process. Implement training and education systems that guarantee the availability of knowledge and skills	Understand/integrate resilience. Develop the ability to adapt. Reflect on and respond to the resilience of the work process. Analyse and solve problems at the system level
Sustainable	Care for the environment	Elaborate resource efficiency

Table 5: INFINEON: main I5.0 directions addressed in the intervention.

4.3.5 Training pilot description.

The following data relate to the training pilot's description. Namely, after completion of the course **Training on KPIs for Logistics in Industry 5.0 Context**, the trainee will be able to

- Recall the characteristics of Key Performance Indicators within a logistics context.
- Explain the impact of Industry 5.0 trends on logistics and KPI relevance.
- Summarise the basic principles of Factory Physics as they relate to logistics operations.
- Apply Factory Physics principles to identify potential improvements in logistics.
- Develop industry-specific KPIs that measure logistics efficiency, flow, and environmental factors.
- Interpret complex data sets to extract meaningful insights related to logistics.
- Assess the effectiveness of KPI-driven decisions in case studies and propose alternative actions based on the data.

After completion of the course **Training on Soft Skills for Successful Communication Interfaces**, the trainee will be able to

- Interpret the principles of effective communication and explain their significance in leadership roles.
- Demonstrate clear and effective communication strategies in varied operational scenarios.
- Describe the components of emotional intelligence and their relevance to managerial effectiveness and team dynamics.
- Evaluate emotional responses in case-study simulations.
- Distinguish the causes of conflict within teams and categorise them according to type and severity.
- Apply conflict resolution techniques appropriate for resolving disagreements.

- Understand constructive feedback and its role in personal and professional development within teams.

At the end of the **TF for the decision-making process, the trainee will be able to apply the acquired complete factory performance knowledge for an efficient decision-making process regardless of** the process area he is assigned to (mentality change).

4.3.5.1.1 Course I: Training on KPIs for Logistics in Industry 5.0 Context

Objective: To enable trainees to develop, interpret, and use KPIs effectively for logistics operations. If applicable, with the concept of "Factory physics" as a framework.

Duration: 6 days, 12 hours in total

Content:

- Introduction to KPIs: Overview of Key Performance Indicators, their importance in logistics, and the impact of Industry 5.0. Explanation of Factory Physics principles
- KPI Development: Step-by-step process for creating significant KPIs that measure logistics efficiency, flow, and environment factors.
- Data Interpretation: Techniques for analysing KPIs to make informed decisions.
- How KPIs influence each other: Understanding the relationship between different KPIs and how changes in one can affect another
- Case Studies: Real-world examples of KPIs in action within an Industry 5.0 framework.

4.3.5.1.2 Course II: Training on Soft Skills for Successful Communication Interfaces

Objective: To focus on essential soft skills for managers such as communication, leadership, teamwork, trustworthiness, adaptability, problem-solving, and emotional intelligence. To enable managers and Team Leads to effectively interface with their teams within the landscape of Industry 5.0.

Duration: 3 days, 12 hours in total

Content:

- Fundamentals of Communication: The importance of clear communication in leadership roles
- Emotional Intelligence: Recognising/managing emotions for better interpersonal interactions.
- Conflict Resolution: Techniques for managing/resolving disagreements within teams.
- Feedback Mechanisms: How to provide and receive constructive feedback

4.3.5.1.3 The Teaching Factory

Additionally, regarding the TF, the problem that the participants face is described below.

The technical background refers to the relevant flow of data coming from highly automated production **areas with different sources** (time ranges and refreshing cycles, formats, point of views), **lacking a proper aggregation** with current applications not being able to provide context-based visualisation of information/knowledge like time, role, topic. The intervention will deliver a **methodology** for developing future models through the introduction of technology that supports the decision-making process (e.g., identifying AI-supported KPIs for efficient decision-making at the factory level).

- Definition of the problem
    - Current applications do not provide context-based visualisation of information/knowledge (time, role, topic, priority,)
    - Lack of the right aggregation of different data sources (time ranges and refreshing cycles, formats, points of view)
- Definition of requirements and Integration of the three Pillars
    - AI-supported visualisation/UI architecture/system
    - AI-supported data provision to ensure an improved decision-making base.

The TF for the decision-making process (3 days, 10 hours in total) is implemented through hands-on practice to gain output for learning and further improvement of the process workflow in terms of decision-making in a real case, making improvements potentially visible and gaining concrete requirements for data-supporting systems or AI-driven technologies.

- Finding an existing workflow with high potential, where the decision-making process is crucial, guided by the following questions:
    - How do decisions come about? What is the path of a decision?
        - Who conducts the individual activities?
        - Who is responsible for?
        - What are the limitations?
        - Which current applications do we use on the way through a decision/process flow?
        - What data is needed to support the decision-making process?
    - In which format?
        - What type of refresh cycle?
        - What requirements are available for data integration, data visualisation and support to make decision-making more efficient?
- Visualisation of a concrete decision-making process using the Picture Card Design Method (PCDM). This method utilises graphics, data, and individually designed cards to create a representation of flexible process models, visualising relevant process indicators such as events, ownership, and data at each stage of the process.
- The result of the PCDM method is the base for the creation of concrete requirements and conclusions by using the brainstorming method and group discussions.
- This base of results is the input for the AI exploration session with the internal Data Analytics & Digitalisation Team, to identify the current application limitations in providing fitting use-case data aggregation and context-based visualisation of needed information.

4.3.5.2 The trainer profiles.

The main theme is related to training on KPIs for Logistics in Industry 5.0 Context. As such, the educational background should be in supply chain management, logistics, industrial engineering, business analytics, or a related field. Advanced degrees can be an advantage, especially if focused on logistics, operations management, or data science, with the additional characteristics:

- Certifications in project management (PMP) or Lean Six Sigma can demonstrate an understanding of process improvement and efficiency. Data analytics or data visualisation certifications, given the emphasis on data interpretation and KPI analysis.

- The industry experience required is mainly related to Logistics and Supply Chain (logistics operations, supply chain management, developing and implementing logistics KPIs).
- Understanding of Factory Physics principles and their application in logistics.
- Previous experience in delivering training sessions, workshops, or seminars with familiarity with instructional design principles.

Effective communication skills are also crucial in clearly articulating complex concepts in an engaging and accessible manner, incorporating interactive teaching methods.

The educational background of the trainers includes psychology, communication, and organisational behaviour. A master's degree or higher can be an advantage, as it demonstrates a deeper understanding of relevant topics such as emotional intelligence and conflict resolution. Additionally, certifications or completed courses in soft skills training, executive coaching, or leadership development can be beneficial.

The industry experience required is mainly related to manufacturing environments, which could help in understanding specific communication challenges. Familiarity with Industry 5.0, including its impact on workplace communication and team collaboration, is a clear added value.

Facilitation skills represent a key element for the successful delivery of this training. This includes the ability to engage an audience through compelling storytelling that effectively illustrates concepts. Additionally, the ability to facilitate open discussions, encourage participation, and manage group dynamics effectively is crucial. Given the type of envisaged training, it is expected to consider a range of training methodologies, including role-playing, simulations, group exercises, and workshops to reinforce learning.

At a personal level, it is requested to have empathy, a high level of self-awareness, and the capacity to build a connection with participants, so that they feel comfortable sharing and learning.

It is also relevant to have (or obtain) expertise in identifying, mediating, and resolving conflicts, with the ability to communicate these skills to others.

4.3.5.3 Preparation of the Training Pilot.

The following are foreseen in terms of preparing the pilot.

- Preparation of learning material & delivery mechanism
    - Material preparation
    - Blended: in presence + online
- Description of learning material and phases

Training on KPIs for Logistics in Industry 5.0 context

<u>Learning material:</u>

- Presentations
- Workbooks/Templates for creating KPIs.
- Access to data analysis software
- Case study materials

<u>Phases:</u>

- Interactive sessions with lectures and workshops
- Group activities for hands-on KPI creation and analysis, reviewed by the trainers for feedback and assessment.

Training on Soft Skills for successful communication interfaces

Learning material:

- Presentations
- Role-playing exercises
- Scenarios for practice in Industry 5.0 settings

Phases:

- Interactive Workshops with role-playing and discussions
- Practising communication scenarios
- Post-assessment to evaluate improvements in soft skills.

Trainer selection

Training on KPIs for Logistics in Industry 5.0 Context: INTERNAL

Training on Soft Skills for successful communication interfaces: INTERNAL

From	May 24 2024	To	June 25 2024

4.3.5.3.1 Expected attitudinal results.

The main topic is to adopt a new approach to handling data from various factory areas. With the previous setting, each person was responsible for one specific area and, therefore, each worker was "confined in his own silo". In the new setting, the person is trained in a decision-making process that is equivalent across different areas, enabling the human resource to work in various areas.

The introduction of a centralised decision-making room is part of an automation process which runs in parallel with the standard setting and represents the first step of its kind at Infineon Austria. All previously employed workers have been relocated to this new working environment.

4.4 Pilot 3 - Kitron UAB / HybridLab: Developing a New Training.

4.4.1 Abstract.

Target groups:

- **Employees**

Involved organisations:

- **Kitron, UAB**
- **Hybrid Labs, UAB**
- **Lithuanian Confederation of Industrialists**

The intervention at Kitron aimed to modify teaching procedures and methods for onboarding employees within I5.0 requirements. It has been conducted in cooperation with HybridLab and the Lithuanian Confederation of Industrialists and has taken place at the Electronics Manufacturing Services (EMS) company Kitron, located in Kaunas, Lithuania.

The main tasks of the intervention are to facilitate new employees with a set of skills to empower them through decision-making and working with digital technologies.

4.4.2 Background. Contextualisation of the intervention.

Contemporary EMS companies are facing challenges in both attracting competitive employees and having sufficient resources to work with digital technologies and complex machinery. High employee turnover hinders resilience and sustainability. Kitron, a leading Scandinavian EMS company, delivers improved flexibility, cost efficiency, and innovation power throughout the value chain.

Specifically, in Kitron, high employee turnover has been observed over the years, resulting in decreased productivity, inefficient labour, and reduced machinery utilisation. However, high turnover is common in the region, regardless of the company segment. This indicates that a human-centric approach is becoming increasingly important.

4.4.3 The situation to change.

Kitron and HybridLab collaborated on the research, after which the onboarding process was selected for change and improvement within Kitron. All new employees in Kitron pass 2-day onboarding learning classes. Currently, the process is too fast and not efficient, and most new employees do not fully absorb the training material, often requiring them to repeat it after starting work in their workplaces. The following areas are to be changed:

- **Training methods.** Several aspects of onboarding training methods require modification. HybridLab's solution is to organise training using a peer-to-peer learning methodology. All new employees are split into groups of three and have different roles: the instructor, the learner, and the observer. The roles rotate so that each member can learn the subject from different angles. Additionally, the training period should be extended to cover the most important knowledge and skills that new employees need to acquire.
- **Implementation of new technologies to engage new employees**. Simulated workplaces will be implemented using augmented reality to enable new employees to

receive training with real-life machinery as much as possible. Additional technologies are to be defined during the implementation process.

- **Review of the training process.** Update the training workflow by optimising the process.
- **Update training material.** Training materials are to be reviewed and updated regularly in accordance with the latest technological developments and process changes.

The intervention has been performed in the phases above, with the potential for generalisation given:

- Definition of knowledge and skills for I5.0.
  The initial task is to define essential knowledge and skills required for Industry 5. This involves identifying the specific knowledge, technical expertise, and soft skills that individuals need to excel in the rapidly evolving landscape of I5.0.
- Definition of new training methodologies for new employees in the Learning Factory environment.
  The next task is to design effective training methodologies. This would be done in cooperation with HybridLab. Critical that the new methodologies were in line with both Kitron's goals and the requirements of I5.0, particularly in the context of Learning Factory environments.
- Implementation phase.
  Defined training methodologies to be implemented at Kitron's factory. This includes changes in the training process, methodologies, supporting technologies, and reviews of training materials.
- Control (evaluation) phase.
  In the control phase, a comparison will be made between the pre-intervention and post-intervention situations. Set of different KPI's to be measured: labour efficiency and utilisation, employee satisfaction, sustainability, and resilience.

4.4.4 Training pilot description.

4.4.4.1 Description of the main industry 5.0 aspects covered by the intervention.

In the matrix shown in the figure hereafter, different aspects of I5.0 that have been covered within the intervention are listed.

	(a) Human	(b) Resilience	(c) Sustainability	(d) Social
A1 Skills	Work with digital technologies Learn new digital technologies Ability to work in different work centers	Learning new employees of automated skills which makes both company and employee more resilient Ability to work in different work centers	Employee awareness regarding recycling importance	
A2 Technologies	Empower through decision making, responsibility through *big picture* vision, more area for decision making	Resilience through new technologies implemented into the learning process (simulated workplace) Additional technologies to be defined during implementation process		
A3 Tasks	Improve in their working area by continuous learning		Recycling tasks	
B KPIs	Standard efficiency	Number of employees available to shift in different work centers	KPI/Recycling audit result (before and after process change) Energy cost per employee	
C Strategies	Continuous improvement			
D Organization				Company social responsibility

Figure 16: KITRON: main industry 5.0 aspects covered by intervention.

In Table 5, there are, underlined in bold, the main directions adopted in the intervention to develop I5.0 workforce skills.

	Creating Industry 5.0	Skills for in Industry 5.0
General	Design and use digital technologies and AI systems in a way that meets Industry 5.0's three objectives	Learn and work with digital technologies. Learn new digital technologies. Understand the basics of complex digital technologies and AI systems.
Human-centric	**Understand human centricity (MANAGERS)** **Support and implement worker participation in decision-making processes (MANAGERS)** **Give control to the shopfloor (MANAGERS)** Use shared control between humans and machines. Use human-centred design methods. Use assistive/supporting/augmenting technologies. Include human-centric values in business models and KPIs, e.g., equality, diversity, and inclusiveness. Include basic humanised values, e.g., freedom, autonomy, self-steering, self-fulfilment (based on evidence-based criteria of job/work design)	**Show responsibility, intrapreneurship (WORKERS)** **Make use of being empowered (WORKERS)** Make use of offered learning opportunities (see also Resilience) **Participate in processes related to (re)design/change (WORKERS)** Act inclusively. **Empower through load reduction/ decision making /.. (MANAGERS)** **Be able to communicate in participation processes (Internal & external interaction) (WORKERS AND MANAGERS)** Working with assistive technologies
Resilient	Assess the company's dependencies through planning for different scenarios and risk assessments. **Develop a resilient production process.** Develop a resilient network of suppliers, partners, and customers (systemic thinking) / supply chain/value chain. **Encourage creativity, innovation, and flexibility/self-organisation.** Implement training and education systems that guarantee the availability of knowledge and skills. Develop strong risk management policies. Develop financial resilience. Include resilience in business models and KPIs	**Understand/integrate resilience.** Understand company policies. **Engage in lifelong learning.** **Develop the ability to adapt.** Develop creativity. Reflect on and respond to the resilience of the work process. Analyse and solve problems at the systems level. **Enable self-organisation; manage yourself**
Sustainable	**Care for the environment.** Carry out environmental impact assessments. Conduct lifecycle assessments. Make and promote 'green choices.' Use green technologies. Develop green tasks. Design and implement circular processes. Include sustainability values in business models and KPIs	**Care for the environment.** Act sustainably Understand circularity. Conduct lifecycle assessments. Conduct environmental impact assessments. Evaluate green technologies. Elaborate on resource efficiency

Table 6: KITRON: main I5.0 directions targeted in the intervention.

4.4.4.2 Trainer.

HybridLab is an educational company that provides hybrid learning and teaching methods. The company offers innovative peer-to-peer simulation training programmes. With its novel programmes for collaborative learning & peer evaluation, simulation facilities and specialised equipment can be utilised 24 hours a day, 7 days a week.

HybridLab uses simulation resources more efficiently and empowers learners to exercise practical small-group peer-to-peer simulation training sessions with direct or remote supervision of the instructors, either synchronously or after the video review (asynchronously). This method offers a well-structured and standardised learning pathway, which encompasses studies on an e-learning platform, peer-to-peer hands-on training sessions in the skill lab or simulation classes using carefully elaborated learning algorithms, direct feedback by peers, and assessment by a remotely working instructor. Mobile technologies and algorithm-driven learning facilitate peer-to-peer learning, offer opportunities to save time and human resources in simulation centres, create unique possibilities for learners to explore the benefits of autonomous and self-regulated learning, and develop new feedback and peer assessment techniques, as well as leadership qualities. Interactive algorithms used in the learning process guide novice learners in a step-by-step manner, helping them create a well-structured mental pathway for decision-making and/or executing the procedure, thereby avoiding any potential learning mistakes.

4.4.4.3 Activities.

The description as well as the schedule of the pilot preparation follow in the next table.

Activities	From	To
Definition of training programme processes (process flow): - **Description of the entire process flow of the training programme** - **Identification of necessary tools and infrastructure**	2024 May	2024 June
Purchase of the necessary equipment and preparation of infrastructure (upgrading classrooms)	2024 June	2024 July
Physical and detailed testing process of the training programme: - **Organisation of a group of testers** - **Coordination and organisation of testing activities** - **Preparation of insights of test process results**	2024 August	2024 September

4.4.4.4 Expected training results.

The main expected outcome is to set up a new onboarding system, which would improve the skills of new employees. Set of skills to be implemented:

Behavioural / Social skills:

- Company values
- LEAN organisation
- Leadership encouragement
- Decision making approach.
- Ability to change work positions.

Technical knowledge:

- EDS Safety/Requirements
- Electromechanical basics
- Documentation reading
- Another basic knowledge

Digital skills:

- IT usage skills
- ERP system usage skills

Employees should be at the centre of managing and running machinery, having wider empowerment for decision-making.

The preparation of the training pilot includes several items, which are summarised in the table hereafter.

Stage	Activities	From	To
Preparation of Educational pilot	Training programme preparation (algorithms, processes)	2024 March	2024 April
	Initial / pilot testing of the training programme: - Defining the required group of testers - Coordination and organisation of testing activities - Preparation of insights and summary of test process results	2024 April	2024 April

The intervention has been being performed in cooperation with HybridLab and the Lithuanian Confederation of Industrialists. The main tasks of the intervention aim at facilitating new employees with a set of skills to empower them through decision-making and working with digital technologies.

Main activities of the intervention planning and implementation project:
- Initial project phase - meetings with project partner Hybridlab to discuss the current situation, methods, and steps of intervention in Kitron.
- Identification and clarification of new training programme and topics (skills required for Industry 5.0)
- Training programme preparation (algorithms, processes)
- Initial testing of the training programme (algorithms)
- Definition of training programme processes
- Physical and detailed testing process of the training programme
- Launch of training programme and implementation in Kitron Practice

4.5 Pilot 4 - COMAU: Human-Robot Interfaces.

4.5.1 Abstract.

Target groups:

- **Mechanical Engineers**
- **Controls Engineers**
- **Project Managers**
- **Sales**
- **Maintenance**
- **Operators**

This intervention focuses on the current scenario of COMAU training activities, with a particular emphasis on I5.0 topics already incorporated and potential future implementations.

The presentation includes a deeper categorisation of the characteristics of the training, such as the topics related to the I5.0 Pillars and the target groups:

- Human centricity/ human inclusion: Human-machine collaboration and Human Autonomy with respect to machine.
- Resilience: Human ability to react to machine downtime.
- Sustainability: Defect reduction, resource efficiency.

4.5.2 Background. Contextualisation of the intervention.

Comau is a company leader in automation and robotics.

Its Academy has training and courses that cover a wide range of topics, teaching different target groups: from elementary schools to universities, from post-diploma to workers/unemployed people who need up/re-skilling.

The main topics are:

- Smart Manufacturing and Industry 4.0
- Programming
- Maintenance
- Collaborative Robotics
- Robotic welding
- IoT, 5G, AI
- STEM
- Exoskeletons
- Visual inspection
- AGVs (Autonomous Guided Vehicle)

The target within BRIDGES 5.0 is the improvement of the training courses, including I5.0 topics, as an active part of the activities.

Current key competences are very focused on Industry 4.0 aspects.

4.5.3 Training intervention.

4.5.3.1 Description.

The pilot is a training focused on an innovative outdoor automation solution to improve quality, performance, and well-being during labour-intensive welding activities.

As described in the implementation section, further below, three different sessions have been implemented.

The objective is to prepare a new workforce to use technology, digitalisation, and innovation within cutting-edge, mobile robotic solutions that will increase production speed and worker well-being by automating traditionally manual processes.

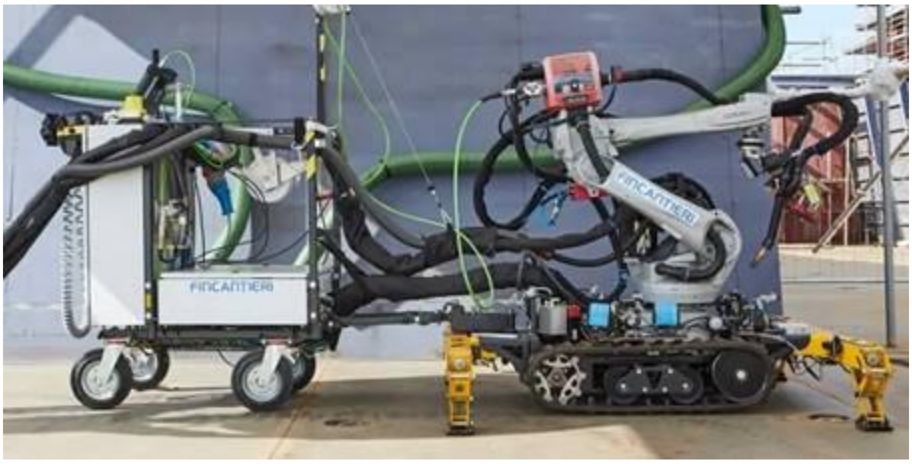

Figure 17: COMAU: main technology used in the intervention.

The problem selected for the TF is the following: "The customer is facing a general shortage in welders. To overcome this issue, he is requesting a mobile robotic welding solution that collaborates with operators".

The training intervention is an adaptation of the VET specialisation programme "Smart Manufacturing". The intervention consists of:

1. An overview of Comau Academy and its training courses:
    a. Academy Overview
    b. Targets
    c. Learning Centre
    d. Professional Training Centre
    e. Model Factory
2. WP5 Teaching Factories 5.0 concepts for companies.

4.5.3.2 Expected training results.

The learning outcomes are:

- Identify the advantages of robotic welding for the Human Workforce.
- Identify the barriers and challenges and be ready to address these during the implementation.

The design of the product is the result of the collaboration between COMAU (an expert in robotics) and the customer (an expert in welding). To some extent, co-creation is already incorporated into the current scenario.

4.5.3.3 Trainers and trainees.

Regarding the trainers, these are the profiles:

- Experts on each technology used:
    - Robotics engineers
    - (Arc-)Welders
    - Vision Systems Engineers

As far as the trainees are concerned, their generic profiles are given hereafter:

- Production engineers
- Software developers
- Technical designer of automation systems 4.0
- Maintenance/installation technicians
- Welders

4.5.3.4 Description of the main I5.0 aspects covered by the intervention.

In the matrix shown in the figure hereafter, different aspects of I5.0 that will be covered within the intervention are listed.

The items included will vary during the design phase of the intervention when a more detailed analysis of the aspects covered will be conducted.

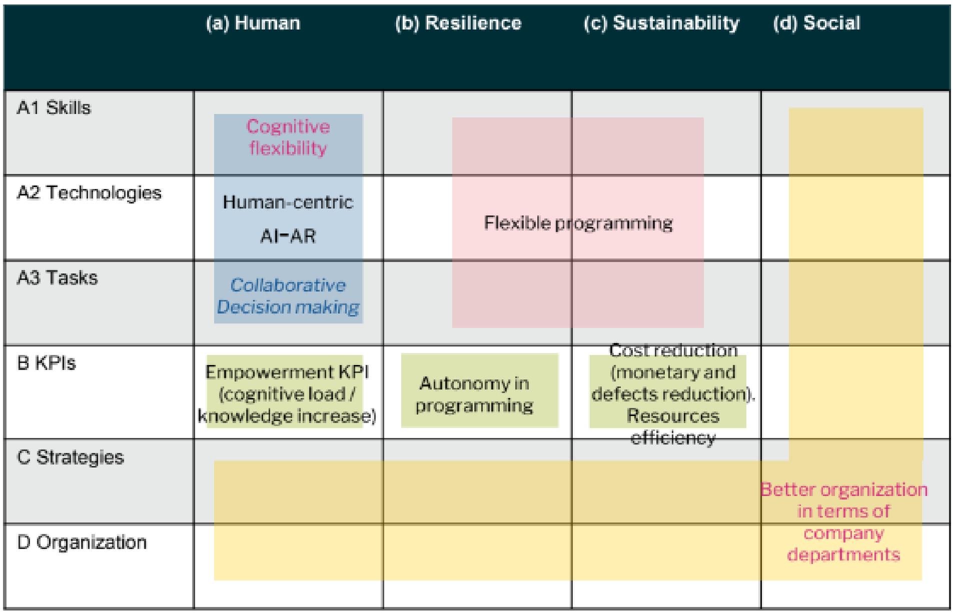

Figure 18: COMAU: main I5.0 aspects covered by the intervention (indicative for the TF case)

The following table includes future aspects of I5.0 to be addressed.

	Create I5.0	Work in I5.0
General	▪ Include human-centric, resilient, and sustainable values in business models and KPIs.	▪ Learn to and work with existing, new, and complex digital technologies and AI systems.
Human-centric	▪ Support and implement worker participation in decision-making processes aimed at change and daily operations. ▪ Empower through load reduction/decision-making and act inclusively. ▪ Apply a human in command-principle with respect to human-technology interaction. ▪ Use human-centred design methods	▪ Participate in processes related to (re) design/change. ▪ Adopt an inclusive attitude
Resilient	▪ Develop a resilient production process. ▪ Develop a resilient network of suppliers, partners, and customers (systemic thinking) / supply chain/value chain. ▪ Encourage creativity, innovation, and flexibility, e.g. by providing learning opportunities for them. ▪ Implement training and education systems that guarantee the availability of knowledge and skills	▪ Understand/integrate resilience into company policies. ▪ Engage in lifelong learning and develop the ability to adapt and to be creative. ▪ Manage yourself
Sustainable	▪ Care for the environment. ▪ Provide the knowledge for workers to do so. ▪ Make and promote 'green choices, use green technologies, develop green tasks, and design and implement circular processes	▪ Care for the environment and act sustainably. ▪ Evaluate green technologies. ▪ Elaborate on resources efficiency

Table 7: COMAU: main I5.0 directions targeted in the intervention.

4.5.3.5 Preparation of the training pilot.

The preparation phase involved:

- Setup and configuration of the educational environment
- Preparation material: manuals, visual content such as slides, e-training by means of a learning management system for the training.
- Customised pilot environment on customer scenario

4.6 Preliminary comparison of the interventions.

The following table summarises the comparison between the case studies. The difference in their needs is apparent, but the convergence in terms of methodology is also significant.

	Sector	Starting point	Foreseen Evaluation	Ecosystem engagement	Learning outcomes
Mondragon	Manufacturing	Digitalisation	Upskilling (case dependent), company level (global, as per annexe 4) and intervention easiness Towards achieving O1-O6	Through technology integration	Related to technology integration
Infineon	Semiconductors	New department creation		Through knowledge management	Related to knowledge passing & transformation
Kitron	Batteries	Reduction of turnover		Through employment	Change Attitude
Comau	Robotics & Automated manufacturing processes	Training system		Through human-technology interaction	Related to technology integration & and developing problem-solving

Table 8 Preliminary comparison of the pilots.

4.7 Partial interventions.

There are further cases under discussion with BRIDGES regarding piloting and utilising consortium members as proxies. The cases are related to the BRIDGES 5.0 company board. These pilots and the corresponding companies are not consortium members. In addition, they are characterised as "partial interventions" since they focus on the pillars that are of particular interest to the companies themselves.

ThyssenKrupp Steel Europe (TKSE) is adapting its vocational education and training system to the needs of digitalisation and decarbonisation. This is performed with the help of ***TU Dortmund and the European Steel Skills Alliance (ESSA)***. Based on the BEYOND4.0 classification of skills for future work (Behrend et al., 2023), this intervention addresses the skill categories of digital skills (digital learning), personal skills (self-determined learning), and social skills (becoming a facilitator to apprentices). Digital learning at TKSE promotes autonomy in (self-directed) education, which enables empowerment of apprentices. For the future, TKSE sees potential in artificial intelligence approaches to support trainers and learners in shaping learning content tailored to individual capacities and competencies.

The intervention of TKSE is an additional qualification in hydrogen technology for apprentices. The target groups are mainly apprentices in technical professions. This additional qualification is due to the fact that TKSE 2026 is introducing Direct Reduction plants, which, initially powered by gas, are increasingly replacing coal-based blast furnaces that use (green) hydrogen in direct reduction plants. Operating the modern technology based on hydrogen requires new skills for workers in the plants. Currently, there is no occupation which specifically includes hydrogen skills. However, German training regulation proves open to different technologies. Therefore, no new occupation is required, but a new additional qualification for hydrogen, which TKSE is providing. The curriculum is being developed by TKSE together with a local university. The matrix shown in Figure 19 lists the various aspects of Industry 5.0 that will be covered within the intervention.

	(a) Human	(b) Resilience	(c) Sustainability	(d) Social
A1 Skills	Digital + personal skills for empowerment (self-reflection of skills-related strengths and weaknesses of apprentices; trainers as facilitators for self-directed learning)		General knowledge on hydrogen for apprentices, train-the-trainer concepts for industrial trainers on hydrogen	
A2 Technologies	Digital learning platforms		Hydrogen Direct Reduction (DR) plants for fossil-free steel-making (usage hydrogen instead of coal)	
A3 Tasks			Changing job tasks due to new ways of steel smelting: from blast furnaces to hydrogen, getting well equipped for installation of DR plant in 2026	
B KPIs				
C Strategies	Enabling individual learning for apprentices, providing learning content to mitigate individual skill gaps		Reducing CO2 emissions by replacing fossil energy sources by hydrogen	
D Organization				

Figure 19: TKSE: focus.

Morrow Batteries is in alliance with the University of Agder (UiA) and the EYDE Cluster; for the Agder region, the challenge of Industry 5.0 is particularly relevant, because they have a large and advanced industry that is in the middle of this transformation, and because they are about to establish an entirely new industry on a significant scale. Many of those who will work in this new industrial reality are not currently found in the workforce. There is no education for many of the things they will be working with, and we have only limited insight into many of the ways in which they will be working in the future. As such, a common initiative is proposed to address and prepare them for these challenges.

Based on the above description, the project *BRIDGES 5.0 AGDER* has the following objectives:

- Preparing skills development for Industry 5.0 (the human side of Industry 4.0): regional skills strategy.
- Define inclusive work life.
- Develop lifelong learning systems (vocational training strategy).
- Attracting an international workforce in the region.
- Learning from others (companies/regions).

Additionally, the following table is valid for the needs of each one of the local stakeholders:

Dimension	MORROW (Teaching factory)	EYDE (Learning factory)
Clarifying goals/intentions	Although Norway and Agder have developed solid labour forces and competences today, there is also a significant need for battery-specific competences to deliver green industrialisation with speed and impact.	The process industry in Norway and Agder is facing significant challenges related to the transition towards sustainability, a circular economy, and technological advancements.

Table 9: UIA: Agder region priorities.

Similarly, **Airbus** has a rich background in human-centricity in the context of Industry 4.0. During the pandemic (COVID-19), aviation and, consequently, aircraft manufacturing were facing profound changes to their business. The demand for aircraft significantly decreased, and the need to improve resilience became apparent. HR4.0 and the general work council have become aware that workers need to acquire skills to improve their ability to adapt to changes and to become more resilient themselves.

Within the Bridges 5.0 project, Airbus Operations focuses on skill development for the Industry 5.0 dimensions of Human-Centricity and Resilience. The dimensions of Sustainability and Social might become more critical when considering the need for skills for "Flying of the Future". The matrix shown in Figure 20 lists different aspects of Industry 5.0 that will be covered within the intervention.

	(a) Human	(b) Resilience	(c) Sustainability	(d) Social
A1 Skills	Improving problem-solving and digital skills to be well equipped for co-creating transformation processes. Social skills (such as communication skills).	Improving adaptability to changes (a.o. digital transformation). Achieving resilience by improved training and education.		
A2 Technologies	Starting with issues/challenges, not with certain technologies	General ability, open to different technologies.		
A3 Tasks	Not only adapting to changes, but co-creating new solutions for tackling current and future challenges.			
B KPIs	Acceptance of new solutions by production workers. Adoption rate and time for new solutions.	Measuring the value of these skills for future changes/challenges. Arguing to managers why they should give time for learning.		
C Strategies		Preparing the organization for current and future transformation.		
D Organization	Fostering empowerment of workers in self-managing teams.			

Figure 20: Airbus: focus.

Finally, regarding **AtlasCopco**, the intervention is organised to improve the overall operational performance in Technical Support. The discussions are ongoing and have not been finalised as of the date of this report.

5 Phase 3 - Implementation of the pilots.

5.1 Introduction.

This section presents the training pilots as they have been implemented. In all of them, towards evaluation, both an initial assessment scheme as well as a final evaluation have been applied in order for the cases to be assessed differentially. Also, it is noted that, with respect to the design, there have been no major deviations in the plan. Table 10 summarises the implementations.

Case	Type	Purpose	Achieved final result	Status in Month 32
Mondragon	Two TFs in two different companies with managers and engineers	To see the level of digitalization adoption and how it can help human centric manufacturing	Realised they need digitalisation and human centricity, change mentality and drive themselves towards a roadmap for technology adoption	Finished design, implementation, as well as evaluation in both ERREKA and FAGOR. In the near future, outside BRIDGES 5.0: potential follow-up with Fagor, about method of driving human centricity and digitalization.
INFINEON	One TF (following classes) with engineers and managers	To transfer decision making to a new fully automated unit	During the pilot, Infineon defined and validated the key data parameters required for decentralised decision-making within the ROCC. This included tool status, throughput metrics, and dispatch priorities, which were integrated into the training content and decision support workflows	Finished design, implementation, as well as evaluation. In the near future, outside BRIDGES 5.0: Will follow up internally with implementing platform to support AI-based decision making.
Kitron	One LF (with classes)	To build a (new) human centric system towards retaining personnel	Integrated Industry 5.0 pillars in internal training system.	Finished design, implementation, as well as evaluation. Outside BRIDGES 5.0: Have already started several extra internal transitions. Will follow up with further enhancement of the internal training.
Comau	One LF emulation with engineers One LF with operators (welders) One TF with engineers and	To adopt human centric technology through automation of welding.	Built LF-based training as a service including Industry 5.0 aspects and at the same time they augmented technology with extra capabilities for future implementations.	Finished design, implementation, as well as evaluation. In the near future, outside BRIDGES 5.0: Will extend further the training procedure for future trainings. At the same time, there is material for the redesign of the technology.
TKSE	One TF-like following internal transitions	To characterise internal transitions to hydrogen and digitalization	Realised the importance of Industry 5.0 existence in both training and full operationalization	Finished design, implementation, as well as evaluation. Internally they will finalize the two transformations (green and digital)

Table 10: Overall implementation details.

5.2 The Mondragon case.

5.2.1 Introductory data on the intervention

The training itself was deliberately focused on fostering reflection on how organisational drivers – specifically the *why, how, and what* of managerial decisions – affected employee behaviour within a given organisational culture. Trainers aimed to maintain this core focus and intentionally avoided diluting the programme with unrelated or complementary practices to preserve the depth and coherence of the intervention's primary learning objectives.

Furthermore, upon completion of the training sessions, participants had the opportunity to provide structured feedback on both the content design and the delivery method of the training. This included aspects such as the balance between theory and practice (e.g., exercises vs. conceptual input), instructional methodology, and overall relevance. These insights were instrumental in refining the intervention for future implementations with other companies, ensuring its continuous improvement and adaptability.

For each of the interventions, the evaluation took place at two moments:

- Before the training intervention (A1): In this case, the evaluation aims to establish a base for the intervention; that is, to measure and assess the previous situation before the intervention. What is the starting point?
- After the intervention (A2): In this case, the evaluation aims to assess the satisfaction and usefulness of the trainees with the training. Was the training interesting? Did the training cover all the crucial issues related to the transition from I4.0 to I5.0?

Furthermore, a third phase is foreseen:

- Several months after the intervention (A3): In this case, the evaluation aims to assess to what extent some organisational practices (related to those worked on in the intervention) were changed/improved.

After taking these three assessment points into account, the schedule for both companies has been the following:

Matz-Erreka:

- A1: September 2024
- A2: December 2024

Fagor:

- A1: January 2025
- A2: March 2025
- A3: December 2025

In both cases, there has been a mixture of engineers and managers as target audience, namely:

- Matz Erreka: 2 engineers, 2 managers (personnel manager and the president)
- Ederlan: 6 engineers, 1 manager (digitalization manager).

Signed informed consents have been gathered from all the participants.

5.2.2 Brief description

As an essential first step in the intervention process, it was useful to identify the specific scenario in which the organisation currently operates. Table 11 graphically presents four distinct scenarios, categorised according to two key dimensions:

1. The Driver of digitisation or automation.
2. The Result of the digitisation or automation process.

The Driver (Table 11) refers to the organisation's underlying motivation for implementing digital or automated technologies. Is the primary objective to enhance performance (e.g. productivity, efficiency), or is the goal more holistic – improving both performance and employee well-being/motivation?

The Result, on the other hand, reflects the actual consequences of digitisation or automation for the workforce. In some cases, technology implementation leads to the erosion of meaningful work: employees are relegated to repetitive, simplified tasks, with automation becoming the dominant force within the organisation. In such cases, technology – not people – becomes the central actor in the company's operations (Weil, 2023).

By contrast, there are situations where automation and digitisation lead to the empowerment of employees, enabling them to take on more cognitive, creative, and problem-solving tasks. In this latter scenario, the worker remains the protagonist, and technology is positioned as a supportive tool that enhances human capabilities. This represents a more human-centric approach to digital transformation (Biondo et al., 2024).

Identifying which of these scenarios applies is critical for tailoring the intervention design, aligning training content with organisational culture and readiness, and setting realistic expectations for change.

	RESULT (as perceived by people): impoverishes ('I lose out')	**RESULT (as perceived by people): empowers ('I have another role; a more important one')**
DRIVER (as perceived by people): 'focus only on performance'	CLASSIC COHERENT SCENARIO. People 'lose out'. Possibly a scenario where the aim is to 'do without people/the human factor'.	HOPEFUL' SCENARIO. The conditions are in place for a work system that minimises resistance (as it empowers people). However, there will be resistance as it requires people to make an effort to adapt and evolve.
DRIVER (perceived by people): 'focus on performance and well-being'.	INCONSISTENT SCENARIO. Contradictions in the system. The aim is to improve performance and well-being, but the design of the digital solution impoverishes people's work.	COHERENT SCENARIO. People gain in well-being and motivation. Technology helps performance but also greater empowerment, with greater development of teams, safe working environments and talent.

Table 11: A two-axis framework, with the overall scenarios.

Depending on the prevailing scenario in each organisation, the proposed intervention required a slightly distinctive design. Therefore, at the beginning of the process at Matz-Erreka and Fagor Ederlan, the matrix, as mentioned earlier, was used to identify the prevailing scenario. In both cases, a 'classic coherent' scenario was detected: that is, a context where people perceive that the driver of automation is exclusively performance improvement and where, as a result, assigned tasks tend to become simpler, more routine, and impoverished. In these cases, automation plays a leading role (the case of ERREKA shown in Figure 21), and people are relegated to being merely an extension of the system.

Figure 21: ERREKA: Indicative photos from the production. SOURCE: BRIDGES 5.0 video from ERREKA (https://bridges5-0.eu/teaching-and-learning-factory-interventions/)

Consequently, as the status quo had to change, the intervention developed had to be in line with the programme defined as ‘scenario 2’ in the section 0. This intervention not only included the development of critical thinking among trainees but also practical experience through the teaching factory methodology.

Below is a summary description of the intervention programme applied.

5.2.2.1 Day 1: Reflections on the rooting of mirror beliefs.

The objective of the first day was to understand the principle of reciprocity described in social exchange theory. The central idea is that change begins with oneself (in this case, managers): the energy for improvement must be directed towards leadership, rather than focusing on changing the visible symptoms of disaffection or resistance that people exhibit.

The reciprocal dynamics between management and people tend to consolidate a set of interrelated beliefs in both groups. These beliefs, called ‘mirror beliefs,’ reinforce each other: what one group believes feeds what the other believes, and vice versa. Thus, ideas such as ‘people don't want to work’ or ‘if you're not supervising them, things don't get done’ tend to take hold in management. Meanwhile, beliefs such as ‘tell me what to do’, ‘that's what you're there for’ or ‘I work my hours and then I leave’ arise among the team.

An illustrative example of how these mirror beliefs operate is as follows: faced with the need to guarantee quality, a traditional organisation tends to appoint a person in charge. This may involve an internal promotion that initially generates motivation and recognition in that person. However, what often goes unnoticed is that this appointment can also create a vacuum of responsibility in the rest of the team. Instead of distributing responsibility for quality, it is centralised. This decision is perceived as logical, given the underlying belief that ‘people tend to avoid work’ or that ‘without someone to supervise, performance drops’. The result: you gain a manager, but you lose involvement from the rest of the group, who respond with phrases such as ‘this isn't my job, that's what the manager is for’. Most importantly, this type of reaction reinforces management's original belief, thus closing the cycle.

This dynamic raised a key question: does this behaviour really reflect what people want? Or is it rather a response to a specific management style that generates disaffection? The intervention points to the latter: this behaviour does not express a genuine desire, but rather reflects a lack of meaning, caused by a traditional organisation based on direct supervision and division of labour.

Over time, these dynamics reinforced a set of beliefs in management (listed in the following table) that directly condition: (i) the way work is organised (in terms of trust or control), (ii) the design of digitalisation (as a tool for empowerment or surveillance), and (iii) the way in which digitalisation is implemented (with greater or lesser participation of the collective). Consequently, at the root of the resistance and limited involvement in digitisation processes, there are these (usually) unquestioned beliefs held by management.

Domain	Beliefs rooted in management
People	They are human resources; necessary to achieve the company's objectives. They are an expense to be minimised to achieve the company's objectives; People do not want to take on more responsibilities
Work	People avoid work; Work is an obligation, something that must be done to earn a living. People work for money; Work is an exchange of time for money. People come to work, not to have fun. Good work is measured by sacrifice, not satisfaction.
The company	The company exists to make money. Everything else is a 'means' to that end; A company that does not grow dies
Management role	It is there to achieve maximum results with the available resources; If there is no clear person in charge, there are no results; It is necessary to be on top of people to guarantee results; Responsible people (or management) are the ones who must have the answers; If one is responsible (or in management), it is because one knows more than the rest (or should know).
The organisation	Specialisation is what guarantees efficiency; The division of labour is the most effective way to manage operations; Everyone has to do their job well; If everyone achieves their objectives in their position, the company will be efficient; If everyone does everything, no one is responsible for anything; With individual objectives, everyone's performance is guaranteed; If there is no pressure, people relax; If people are left to decide, there is a high risk of losing control. It could be chaos. The more control, the more efficiency.

Table 12: Domains and beliefs.

5.2.2.2 Day 2-3: Reflections on the DRIVER and the RESULT.

The second day of the intervention aimed to understand two key factors in the digitisation or automation process: (i) the driver (original motivation for change) and (ii) the Result, or impact of this process on people's work.

***The Driver**: Performance alone... or well-being and performance?*

Given the complexity of management, the usual tendency is to address problems by dividing them: first, performance is prioritised and, at a later stage, if necessary, well-being is addressed. This sequential and reductionist approach, however, can lead to ineffective or even counterproductive solutions (Ackoff & Emery, 1972; Senge, 1995), as it ignores systemic dynamics and the interrelationships between the technical system and the social system, often amplifying problems rather than solving them.

In practice, many organisations initially design operational strategies focused on productivity. When these strategies generate negative side effects on well-being, corrective measures are applied afterwards. This approach reveals a tactical view of people, seen as means to achieve results rather than ends in themselves.

As an alternative, the intervention proposed the socio-technical approach (Trist & Bamforth, 1951), which suggests balancing the needs of the technical system and the social system, considering both as interdependent. Instead of addressing performance first and then well-being, the intervention advocates addressing both objectives together from the outset: an equation with two unknowns that must be solved simultaneously.

***The Result**: Impoverishment of work... or meaningful work?*

What would happen if management started from a perspective that recognised human nature? This perspective involves assuming that people are not just resources, but human beings with a series of universal traits – shared across cultures and contexts – that should guide organisational and technological design.

Recognising these traits helps to design more motivating and humane work environments. During the intervention, the hypothesis was put forward that organising work in line with these principles allows for the construction of more 'human-centric' organisations, also facilitating the adoption and effectiveness of digitisation processes.

Four universal traits with high organisational impact were discussed, supported by self-determination theory (Ryan & Deci, 2000) and studies on meaningful work (Rosso et al., 2010):

- Social connection: Its absence leads to dissatisfaction. Loneliness or isolation damages well-being (Baumeister & Leary, 1995).
- Autonomy and agency: deciding on one's own work reinforces self-determination (Deci & Ryan, 2012).
- Exploration and learning: Curiosity drives continuous improvement and innovation.
- Purpose or altruism: Having a positive impact on others through work is a source of intrinsic motivation (Pink, 2010; Rosso et al., 2010).

During the session, participants discussed how to meet these needs through specific organisational practices that enable the creation of more meaningful work contexts, moving towards a more people-centred organisation.

5.2.2.3 Day 4: Teaching factory of "the system" as the level of analysis.

Finally, the last day of the intervention was devoted to a practical Teaching Factory exercise with the trainees. The aim was to translate the reflections of the previous days into two key areas: (i) the creation of working environments that simultaneously promote performance and well-being, and (ii) the improvement of digitisation processes from a people-centred perspective. The session began with a double question that guided the work: How can we build more human-centric work contexts? How can we facilitate the adoption of technology by people?

To address these issues, a brief review of the key ideas developed so far was conducted, which served as the basis for adapting the exercise to the specific reality of the participants. The central ideas were:

- Change starts with oneself (leadership and management). This means stopping intervening in the visible symptoms of disaffection in the group (e.g. through training or supervision) and focusing energy on reviewing one's management framework.

- The phenomenon is multifactorial, so the appropriate level of intervention is not isolated practices, but the interrelated set of practices: the operating system. The unit of analysis is therefore the system of practices, not specific actions.
- Underlying beliefs condition day-to-day management. All management actions are based on a philosophical framework – conscious or unconscious – that guides the design of the work and the management style. Therefore, reviewing these beliefs is key to redesigning the operating system.
- Seek simultaneous gains in performance and well-being. This means overcoming the traditional sequential logic ('first performance, then well-being') and adopting a more integrative vision, in which specific organisational practices have a positive impact on both aspects simultaneously.

With these premises in mind, an exercise based on the Teaching Factory was proposed, aimed at reviewing the work system of each team. This concept, inspired by Dignan's model (2019), refers to the set of daily practices that define 'how the organisation operates' and shape the environment in which both work and automation processes are carried out. The redesign of the operating system thus seeks to create environments that are more consistent with human-centric logic, from which to promote sustainable and meaningful digitalisation.

5.2.3 Results of the training.

5.2.3.1 Questionnaire.

Question	Evaluation	Classification	Scale
Q1	Do you have an idea about why people disengage in the company?	Human Centricity	1-5 Likert scale 1 Not at all 2 A little 3 neutral 4 Quite 5 Very much
Q2	Do you have an idea of what CRITERIA to use as a guide for implementing human-centric initiatives?	Human Centricity	
Q3	Do you know the organisational practices that can help develop a more human-centric organisation?	Human Centricity	
Q4	Do you feel you have more knowledge about how to digitise/implement a modern technology?	Human Centricity	
Q5	Do you know how to improve organisational flexibility (performance) while achieving a more human-centric organisation?	Resilience	
Q6	Once digitised, do you feel confident using production optimisation to improve environmental sustainability?	Sustainability	
Q7	Do you feel confident using production optimisation to improve waste reduction?	Sustainability	

Table 13: MONDRAGON: final questionnaire used for upskilling.

5.2.3.2 ERREKA.

For the case of ERREKA, the mean values of responses follow. The results regard averages of differences in Likert question. An increase from pre- to post- assessment implies positive results, i.e. in Q1, there was an increase in awareness about ways of disengagement.

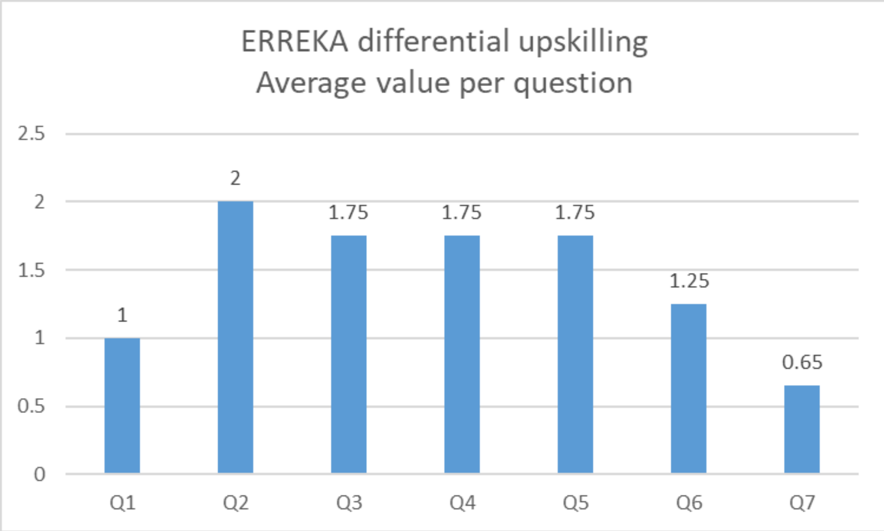

Figure 22: ERREKA: results for upskilling (The jamovi project, 2022) (Input from trainees, High score is successful upskilling).

Following the intervention, ERREKA is taking steps to implement digital technologies on the shop floor. They possess the necessary know-how and have a clearly defined roadmap for doing so.

5.2.3.3 FAGOR.

For the case of FAGOR the mean values of responses follow below. The results regard averages of differences in Likert question. The impact of training is evidently different than in ERREKA. In particular, the absence of a pathway is reflected in the lower average of responses in Q4.

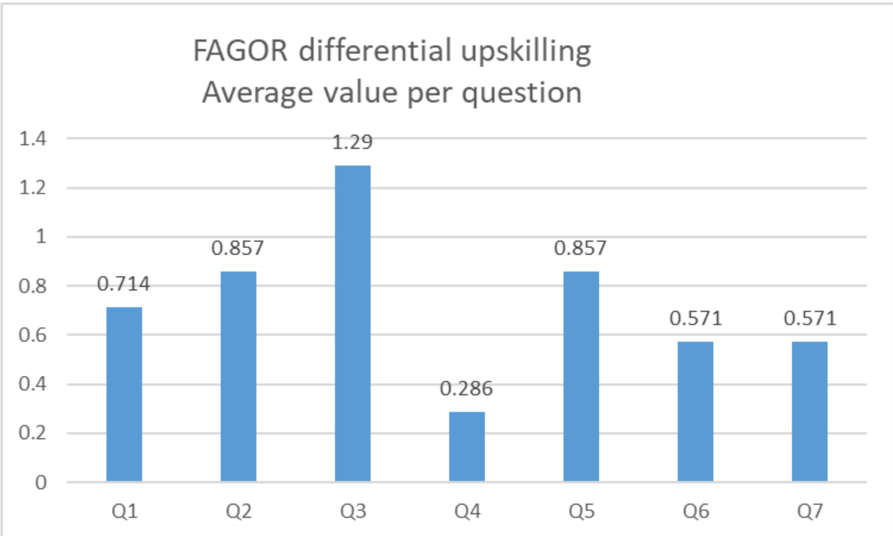

Figure 23: FAGOR: indicative results for upskilling (Input from trainees, High score is successful upskilling).

Further elaborated results of this survey are shown aggregately per pillar in the next section (6.2).

FAGOR, by contrast, has recognised the need to reassess certain aspects of their approach. In fact, they may need to develop a concrete transformation framework (TF) by the end of the year. In collaboration with Mondragon University, they have already begun work on longitudinal measurements across all plants, using a survey planned for September 2025. In practice, greater worker adoption of the implemented technologies still needs to be achieved in order to maximise their potential. Given the size of FAGOR, the pathway forward remains less clearly defined.

As such, with respect to qualitative outcomes, in FAGOR, implementation can be characterised partially successful. While managers participated fully and showed conceptual engagement, practical application was limited. This suggests a need for stronger anchoring mechanisms post-training.

5.2.3.4 Outcomes.

For both companies, the immediate outcomes with respect to the underutilisation of digital technologies and the behaviour of the participants, according to the companies themselves, have been the following:

- Change of mentality
- Agreement towards integrating digital workflows.
- To achieve a greater use of the technology by workers will enable the company to be more resilient and competitive. At the same time, workers will gain in wellbeing.

5.3 The Infineon case.

5.3.1 Introduction.

Thirteen trainees have taken part in the intervention. They represent different roles at Infineon, ranging from Shop Floor to Management. The background is Engineering. The level of expertise and seniority is high. For more details, refer to the summary table below. Informed consents have been gathered.

Stakeholder group	Functional level	Number of people	Role at ROCC	Knowledge background	Activity portfolio
Line Expert	Production logistics expert	4	Shopfloor	Experienced production expert	Logistic monitoring, Prioritisation, Problem coordination
ROCC experts	Workflow expert Data expert	4	Technical support	Engineers	Knowing procedures, Technologies configurations and Visualisations (e.g. Tableau)
Management	Team Lead	2	Line organisation	Senior engineers	Accountable for several activities in a process area, Leading teams

Management	Team Lead	3	Functional organisation	Senior engineers	Accountable for overall production-relevant KPIs, Leading teams

Table 14: INFINEON: participants' details.

The following schema summarises the structure and the timeline of the pilot.

Type	Course: Training on KPIs for Logistics in Industry 5.0 Context	From	Jan 25	To	Jan 25
Type	Course: Training on Soft Skills for successful communication interfaces	From	Feb 25	To	Mar 25
Type	TF for the decision-making process	From	Apr 25	To	Jun 25

Table 15: INFINEON: the structure of the pilot and the dates.

5.3.2 Brief description of the actual training.

The training pilot was structured into three integrated components, as planned, aiming at supporting a human-centred transition to Industry 5.0 within a highly automated production environment.

The first component consisted of a technical training session that included five lessons: an introduction to KPIs and Industry 5.0, factory physics principles, a KPI development workshop, data interpretation techniques, and the interconnectivity of KPIs.

This session provided participants with a robust analytical foundation for understanding and shaping performance metrics in modern manufacturing.

The second session focused on soft skills essential for human-machine collaboration, covering communication fundamentals, emotional intelligence, conflict resolution strategies, and feedback mechanisms.

Together, these two sessions ensured that participants were equipped not only with the technical tools but also the interpersonal capabilities necessary in a socio-technical system.

The third and concluding component was a Teaching Factory module, designed as an experiential learning environment where participants applied their knowledge to evaluate and select AI tools that support decision-making in real production contexts.

This first-hand problem-solving experience fostered system-level thinking and empowered participants to actively contribute to the design and implementation of human-in-the-loop AI solutions.

5.3.2.1 Training on KPIs for Logistics in Industry 5.0 context.

The training was conducted through a series of presentations, alternating with group discussions and activities. For the latter, there are direct activities, "homework" for consolidating the knowledge and a group presentation of a fictional case. The following bullet points elaborate on several aspects of the conducted lecture, as this was implemented:

- Questions posed by the trainers are applied to a practical example to verify that the trainees understand it.

- Tried to replicate application of KPIs within the current software, with examples --> tried to connect daily work with usage of these KPIs, different feelings/feedback thanks to the varied audience.
- Very vibrant exchange of opinions, trying to “validate” said points to confirm (or not) the understanding of what has been taught.
- (Whiteboard) exercise with real numbers and direct applications of just learnt KPIs.
- Clear and understood connection with the following classes.
- Live use of software, directly addressing questions through examples (sandbox environment)
- Example of companies from other sectors (Amazon, Volvo, Airbus) using this principle for their logistics and highlighting the positive outcomes and results
- Group activity: 2/3 people groups prepared and discussed a project, applying the learnings to a Project Charter
- Presentation from each group + discussions/brainstorming with another group, bringing in potential solutions/ideas.

5.3.2.2 Training on Soft Skills for Successful Communication Interfaces.

The training was conducted through a series of presentations, alternating with group discussions and activities. The following bullet points point out some details of the activity implementation:

- Groupwork on Insight Discovery (which “type” am I?) --> used as a “tool” to verify the understanding through guiding questions + consequent presentation and discussion
- Quality problem scenario: 3 working groups to find the root of this problem (mind mapping, brainstorming, reverse thinking); used to verify the understanding of the class a subsequent presentation to the other colleagues.
- 5-why method from Toyota
- Always opening the class with “rehearsal” of what has been done last time (way of validating the learnings, monitoring)
- Some trainees also “stood up” and try to offer solutions/examples to contribute to the topic and share knowledge with other trainees.
- A colleague who was not present in the previous class is given information from the last class from the trainees themselves, under the supervision of the trainer --> another method for monitoring the understanding of the group.

5.3.2.3 Workshop on Teaching Factory for the decision-making process.

The practical session was executed through a series of workshops, group discussions and group activities. The following details refer to the activities pertaining to the implementation of the TF:

- Understanding methodology of Picture Card Design Method (PCDM) in combination with the techniques of value stream analysis; knowledge is created/improved to enable fast and fully visible process flows, in terms of decision-making processes.
- The two groups brainstorming at the beginning was worthwhile to find a cross-over workflow in the range of their core responsibilities/tasks and created awareness to see the biggest overlap for all involved parties/groups/persons in the training.
- For most, especially non-management persons, it was an entirely new way to prepare for improvement in known procedures, including creating transparency and visibility of data usage, formats, roles, decisions, status changes of the flow and differences in working procedures/interpretations, and sequence between production areas of the same problem. A new level of transparency was created by the chosen use case, “tool down”, and its decision sequence, including all parameters along the flow. This results

in a possible view of enriching awareness of process strengths and weaknesses, risks, and opportunities.

- In the second stage of the group working session, the complete application portfolio was described, including which data is relevant for which role, and in which format the data is provided. The overlap of the different sources used yielded a comprehensive picture of the data landscape.
- To create prioritisations of big or low-hanging potentials for improvement, and weaknesses in terms of wasting time, resources, spending manual (but automatable) or double effort, the chosen use case flow was reviewed again in a group session. The results showed that for all organisations, a general, but individually adjustable (based on process-specific parameterisation) set of data is needed during the decision-making process; this was considered by the group to be the biggest improvement potential.
- Based on that, the whole team decided to specify, on a technical level, which data is exactly needed for the decision-making process in terms of the chosen use case of a “tool down”. Ultimately, a pool of concrete descriptions of data, including their aggregations and dependencies on one another, was presented.
- Afterwards, the AI-application evaluation was performed in collaboration with the Data Analytics and Digitalisation Team. The goal has been to understand together the needs of the group in terms of concrete requirements (coming from the previous step) for a simple, intelligent data aggregation platform.
- In addition to that, the working sessions showed distinct aspects of complexity and diversity/differences in the organisation:
    - Interpretation and execution of decision-making processes of the same use case, cross over the different production areas with the same role responsibilities
    - Use of tools and data sources of the same kind of information
    - Responsibility splitting, of logistics and processes, is relevant for working on decision-making processes.
    - A big application portfolio leads to misinterpretation or different meanings and creates a different mindset of the exact scope of problems.

Figure 24: INFINEON: pictures form the sessions.

5.3.3 Results of the training.

5.3.3.1 Questionnaire.

Question	Evaluation	Classification	Scale
Q1	Do you feel confident in solving problems during the manufacturing process?	Human Centricity	1-5 Likert scale 1. Extremely low 2. Moderately low 3. Neutral, neither high nor low 4. Moderately high 5. Extremely high
Q2	Do you feel confident in using shared control between human and machine?	Human Centricity	
Q3	Do you feel confident in working on multiple projects simultaneously?	Resilience	
Q4	Do you feel confident in working in different areas of the company?	Resilience	
Q5	Do you rate the new organisation setup more fulfilling than before?	Sustainability	
Q6	Do you feel that the organisation setup helps you in making your decision-making process better (communication interface, hardware/software tools, empowerment?	Sustainability	

Table 16: INFINEON: final questionnaire used for upskilling.

5.3.3.2 Survey results.

The results of this survey are shown aggregately per pillar in the next section (6.2).

For the case of INFINEON, the mean values of responses follow below. The results regard averages of differences in Likert question (i.e. increase from pre- to post- assessment, so positive results are positive).

Interestingly enough, the negative mean value in Q3 may reflect an important realization among participants: while multitasking and cross-project involvement are common in deep-tech industries such as semiconductor manufacturing, they also pose significant operational and cognitive challenges. This is backed up by literature and is due to mainly the number of simultaneous projects is a strong predictor of work interruptions and multitasking overhead, which can negatively impact team efficiency and project timelines (Tregubov, 2018).

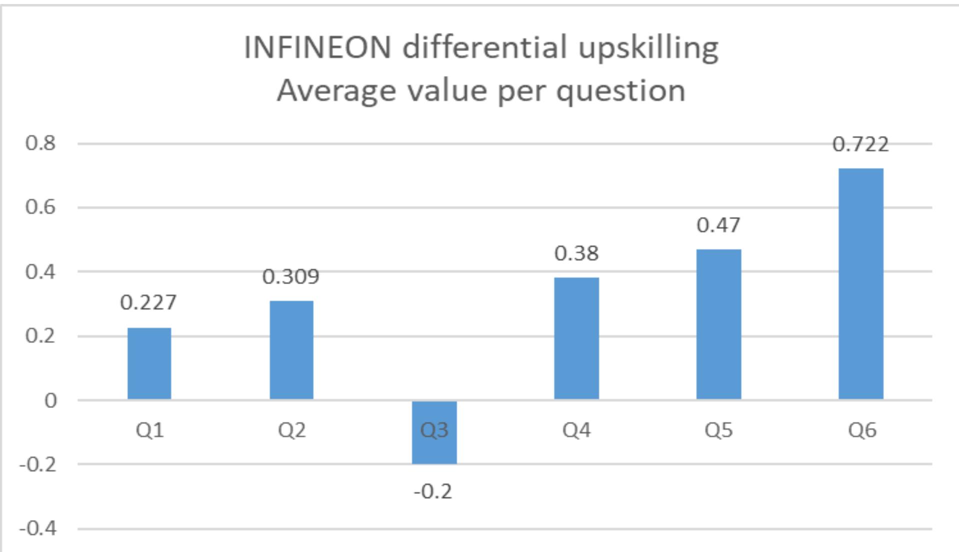

Figure 25: INFINEON: upskilling results for (averages; Input from trainees, High score is successful upskilling).

5.3.3.3 Outcomes.

The immediate outcomes with respect to transferring decision making to new unit, according to the company, are:

- The designed data ontology to start designing and implementing a multi-fold AI decision-support system.
- Enhanced communication skills
- Increased knowledge due to KPIs-related material

Also, the new model of decision making has been proved useful for the new unit, even if some complexity has been added, as shown by the testimonies in the table hereafter.

Type of response	Do you rate the new organisation setup more fulfilling than before?	Do you feel that the organisation setup helps you in making your decision-making process better (communication interface, hardware/software tools, empowerment)?
Average quantified opinion (Likert scale)	Average of 4.11 in the scale • 1 strongly disagree. • 2 disagree. • 3 neutral • 4 agree. • 5 strongly agree. SO, THEY AGREE	Average of 4.22 in the scale • 1 strongly disagree. • 2 disagree. • 3 neutral • 4 agree. • 5 strongly agree. SO, THEY AGREE
INFINEON	It has become much clearer with the new organisational structure. You also have an overview of the entire line, not just your department.	Yes, by working as a Line Expert, you serve as the interface between Maintenance, Unit Process Engineer, Operator, Shift Lead, and others. Because this has been communicated concretely, decisions are made more easily, quickly, and logically.
INFINEON Question	I like the work in the ROCC, but we are now getting more pressure from the Line Control compared to the previous operational setting, when the daily interaction was seldom	The ROCC has significantly improved communication between all departments, which was previously almost non-existent.

Table 17: INFINEON: testimonies and opinions from trainees about the new workflow.

5.4 The Kitron case.

5.4.1 Introduction.

The training in Kitron took place in different batches, as new employees arrived, from December 2024 to March 2025. In total, 16 trainees were evaluated. Courses with HybridLab were used to acquire knowledge on unconventional learning methods, as per the procedures described hereafter.

All trainees have signed informed consents.

5.4.2 Brief description of the training.

As aforementioned, the internal intervention has been aiming to change the teaching process and methods of onboarding employees at Kitron in accordance with the requirements of Industry 5.0. Important and relevant topics have been refined and included in the new training programme, as per the table hereafter.

No.	Training topic:	Skills to be implemented	Related Industry I5.0 directions / pillars
1	Introduction about Kitron (e.g. company values, history, structure, leadership encouragement events and initiatives)	Behavioural / Social skills	Continuous improvement / company social responsibility
2	EDS Safety/Requirements	Technical knowledge	Resilience
3	Environmental protection, LEAN (5S), occupational safety	Behavioural / Social skills	Recycling audit results / Energy cost per employee
4	Electromechanical basics (e.g. Terms and classification of components)	Technical knowledge	Resilience
5	Manufacturing Execution System usage skills	Digital skills	Resilience
6	IT usage skills (e.g. Intranet, cyber security, email, IT help desk etc.)	Digital skills	Resilience
7	Quality management system (e.g. ISO standards)	Technical knowledge	Human / Social
8	Documentation reading	Technical knowledge	Human / Resilience
9	ERP system usage skills	Digital skills	Resilience

Table 18: KITRON: training structure.

Furthermore, several aspects of onboarding training methods have been changed during this intervention project. HybridLab offered, trained, and, together with the Kitron team, applied the solution to organise trainings using a peer-to-peer learning methodology in Kitron UAB. All new employees are now split into groups of three and have separate roles: the instructor, the learner, and the observer. The roles are rotating so that each member can learn the subject from different angles and perspectives. The effectiveness of such methodology was scientifically proven, and it also works in Kitron UAB (Electronics manufacturing services) environment:

- Implementation of modern technologies to engage new employees. Simulated workplaces (training class) were created to learn new skills in practical / work-related situations. Mobile applications (apps) on tablets and computers are used for both learning theoretical topics and performing practical tasks (algorithms) in groups.
- Review of the training process. The training workflow was updated by optimising the process (the most essential nine topics were identified and included, and excess information has been removed from the previous training material).
- Update training material. The training material was reviewed and updated according to the latest technological developments and process changes, as well as best practices from HybridLab company. Tasks (algorithms) for practical situations have been created, developed, and assessed by different types of employee groups (e.g., SMT line operators).

Figure 26: KITRON: indicative photos from the processes of the tasks (top) and of the training procedure (bottom).

5.4.3 Results from the training.

5.4.3.1 Questionnaire.

Question	Evaluation	Classification	Scale
Q1	I am familiar with 3 main values of the Company	Conceptual (Internal)	1-5 Likert scale 1 strongly disagree. 2 disagree. 3 neutral
Q2	I know how to behave in the workplace in compliance with ESD safety	Human Centricity	

Q3	I understand the principles of lean methodology (5S principles)	Sustainability	4 agree. 5 strongly agree.
Q4	I know how to sort hazardous production waste	Sustainability	
Q5	I understand how to identify the direction of an electronic component	Human Centricity	
Q6	I know what is „X" information system and how to use it in practice	Resilience	
Q7	I know „IT security standards" in the company and understand their importance	Resilience	
Q8	I understand the meaning and importance of production documentation (product assembly instruction)	Resilience	
Q9	I know what is „Y" information system and how to use it in practice	Technology (Internal)	
Q10	I feel confident and I know how to sort waste in my daily routine*	Sustainability	
Q11	I feel confident when working in different working areas (operations) in the company	Human Centricity	
Q12	I feel confident when communicating problems to other team members / supervisors	Human Centricity	

Table 19: MONDRAGON: final questionnaire used for upskilling.

5.4.3.2 Survey results.

The results of this survey are shown aggregately per pillar in the next section (6.2). The average upskilling, however, is shown hereafter.

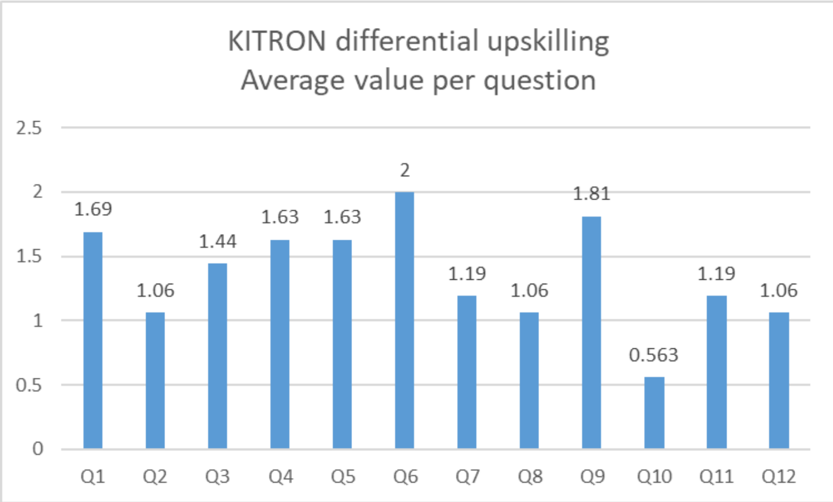

Figure 27: KITRON: results for upskilling (Input from trainees, High score is successful upskilling).

5.4.3.3 Outcomes.

The immediate outcomes with respect to the need of KITRON for focus on turnover, according to Kitron, are:

- Better informed of the processes and the procedures
- Better communication
- Facilitation of workflows
- More interesting work
- Successful intervention would add to strategic growth ambition, through ability to have solid background for rapid skilful employee increase.

Better efficiency will come based on better communication and the fact that they will be prepared. However, this is hard to verify, since other transformations have started in the meantime.

5.5 The Comau case.

5.5.1 Introduction.

The main structure of the pilot involved addressing technological issues on the welding configuration, namely:

- Components and Safety-DPI
- Machine (robot + undercarriage + welding machine) procedures
- Welding configuration
- Undercarriage movements configuration
- Calibration, reset and warnings management.
- Troubleshooting
- Final Checks and evaluation

Three different sessions were implemented, each with distinct methods, outcomes, and target audiences.

- The first one emulated a learning factory with 12 engineers as trainees. This took part in July 2024.

- The second one was the main part, where 8 real operators (welders) were trained, utilizing more focused Learning factory, as shown in details hereafter. This training occurred in the premises of the end user in October 2024.
- Finally, a redesigning of technology was brainstormed, in terms of a Teaching Factory, utilizing 13 engineers and designers, in April 2025.

Each one served a specific purpose (emulation, actual training, re-design of technology) and the details are given hereafter.

Informed consents have been gathered from all the trainees.

5.5.2 Brief description of the training.

5.5.2.1 Embracing Industry 5.0 in augmented traditional training with hands-on project (LF-like).

On 31 July 2024, a group of professional trainers came together for a half-day training course (TF) designed to turn Industry 5.0 concepts into a practical reality. The agenda included theory, reflection, and hands-on experience with an autonomous, intelligent robotic welding system. A concise summary of the four sequential sessions is provided below.

We began with a brief overview of Industry 5.0, the next stage in the evolution of Industry 4.0, which puts people and the planet at the heart of production. Key themes included human-robot collaboration, smart personalisation, sustainability, and resilience. There was a productive discussion about how trainers can incorporate these principles into curricula to prepare technicians for deeply integrated cyber-physical workplaces.

Before delving into more detail, participants completed a brief questionnaire to assess their existing familiarity with Industry 5.0 terminology and their perceptions of the associated challenges and training needs. These responses provided a useful initial benchmark that informed the focus of subsequent discussions.

The core of the training was a guided introduction to our autonomous intelligent robotic welding system. Trainers go through different features:

1. System Anatomy - hardware “journey” and safety protocols.
2. Programming & AI - demo of adaptive path planning and real-time quality monitoring.
3. Practice Run - each trainer set parameters and executed a weld, experiencing the human machine interface first hand.

Ultimately, everyone had witnessed how AI-driven sensing and autonomous adjustment resulted in cleaner seams, reduced rework, and safer workflows.

To capture fresh impressions, participants were asked to complete the questionnaire a second time. Early reviews revealed a significant increase in confidence when it came to explaining Industry 5.0 concepts and incorporating robotic welding examples into their own training modules. Detailed feedback will guide follow-up resources and advanced workshops.

Training Highlights:

- Human Centric ≠ Human Less: Technology amplifies, rather than replaces, the trainer’s role.
- Data Driven Teaching: Pre /post questionnaires spotlight learning gaps and wins in real time.
- Safety First: Mastering safety interlocks and emergency stops is step one before any tech deep dive.

5.5.2.2 Industry 5.0 in Action – LF Session.

A select group of the customers' in-house trainers gathered for a one-day workshop to explore and experience our autonomous, intelligent, human-robot collaborative welding system. The agenda combined conceptual groundwork with practical experimentation. Below is a concise overview of the four sequential sessions.

We began by exploring Industry 5.0, the stage at which smart machines, AI and people collaborate to create more personalised, sustainable, and resilient production. The discussion focused on how human-robot teaming can improve both quality and job satisfaction on the shop floor.

Key point: In Industry 5.0, the robot becomes a skilled partner that adapts to human intent, rather than the other way around.

Participants completed a short questionnaire that probed their current understanding of Industry 5.0 concepts, welding automation, and training challenges. The anonymous data provided a benchmark that informed the live emphasis throughout the day.

At the heart of the workshop, each trainer was given an opportunity to experience the controls of the autonomous, intelligent, human-robot collaborative welding system.

1. System Walk Through – hardware layout, safety interlocks, and ergonomic co-working zones.
2. Adaptive Programming Demo – observing the AI refine torch paths based on real-time sensor feedback.
3. Practical Trial – each trainer configured parameters, initiated a weld, and watched the robot self-correct for optimal bead quality.

The live demonstration showed how vision sensors, force control and predictive analytics work together to produce consistent, high-quality seams and reduce the need for rework.

Immediately after the laboratory session, the trainers completed the questionnaire again to capture their fresh insights. Early results suggest that confidence in explaining the benefits of Industry 5.0 and operating the collaborative welder safely has increased significantly.

LF Highlights:

- Human Centric Safety: Smart force limiting and visual cues made co-working feel intuitive and secure.
- Skill Amplification: The system's AI managed routine precision, freeing trainers to focus on teaching best practice techniques.
- Data Driven Progress: Comparing pre- and post-survey scores surfaced learning gains and targeted next step topics.

5.5.2.3 Improving the Collaborative Welding – Designer and Trainer TF.

A cross-functional group of solution designers and corporate trainers convened for a focused workshop dedicated to enhancing our autonomous, intelligent, and human-robot collaborative welding system through the lens of Industry 5.0. The sprint involved rapid assessment, principle-driven ideation, and data-backed reflection. The structured recap is provided below.

- Participants opened the TF by completing a brief digital survey designed to capture:
- Current familiarity with Industry 5.0 tenets
- Perceived strengths and pain points of the existing welding solution

- Priorities for human-centric design improvements

After a brief reminder of the pillars of Industry 5.0 (human-centricity, sustainability, and resilience), the group took part in two activities:
The design leads showcased the current hardware, AI toolchain and operator interface.
Participants then identified ways in which the system could better embody Industry 5.0, such as ergonomic co-working zones, energy-aware cycle logic and explainable AI prompts.
To close the loop, participants retook the questionnaire, now focused on:

- Confidence in integrating Industry 5.0 into design cycles.
- Alignment on the top three system enhancements

TF Highlights:

1. People First, Specs Second: Ergonomics and intuitive UX ranked higher than raw weld speed gains.
2. Transparency Drives Trust: Explainable AI suggestions are essential for shop floor adoption.

5.5.3 Results of the training.

5.5.3.1 Questionnaire.

Question	Evaluation	Classification	Scale
Q1	How informed are you about the technology subject of the course?	General	1-5 Likert scale 1 Not at all 2 A little 3 Neutral 4 Quite 5 Very much
Q2	How much do you think that the use of a robotic welding solution will have on your role as an operator, considering that the machine will do physical work?	General	
Q3	How much do you think that the implementation of this technology can improve the quality of the welding operations?	General	
Q4	How much do you feel prepared to deal with the introduction of this new, bombastic welding technology in your role as an operator?	Human Centricity	
Q5	How much do you expect that your role as an operator will change with the introduction of modern technology for robotic welding?	Human Centricity	
Q6	How important is it for you to have adequate training to manage and supervise the activity of the technological solution?	Human Centricity	
Q7	How much do you think you have the skills necessary to adapt to the new role that the use of this modern technology for welding involves?	Human Centricity	
Q8	How much do you think that collaboration with this modern technology will make your job more satisfying?	Human Centricity	

Q9	How important is it to you that the welding technology is efficient from an energy perspective?	Sustainability	
Q10	How much do you think the use of a technological solution can help reduce material waste during welding, considering a change in the working process?	Sustainability	
Q11	How important is it for you that the robotic welding technology contributes to creating a safer work environment?	Sustainability	
Q12	How much do you think that the introduction of a technology for robotic welding can make the production process more robust in the face of unexpected events (e.g. lack of qualified personnel, ergonomic problems, ...)?	Resilience	
Q13	How important is it to you that the technological solution is designed to be easy to use, maintain, and repairable in case of problems?	Resilience	
Q14	How much do you think this technology can improve the continuity of welding operations?	Resilience	

Table 20: COMAU: final questionnaire used for upskilling (sessions 1 & 2).

5.5.3.2 Survey results.

For the case of the LF (second training), the results on average upskilling per question follow below. It is noted that that according to questions Q12-Q14, the impact of training on resilience was zero, backing up the observation of the operators not internalising the concept of resilience. The upskilling, related to technology-related questions Q1 and Q4, however, have high averages, however, questions like Q2 and Q3 show marginal impact in terms of averages.

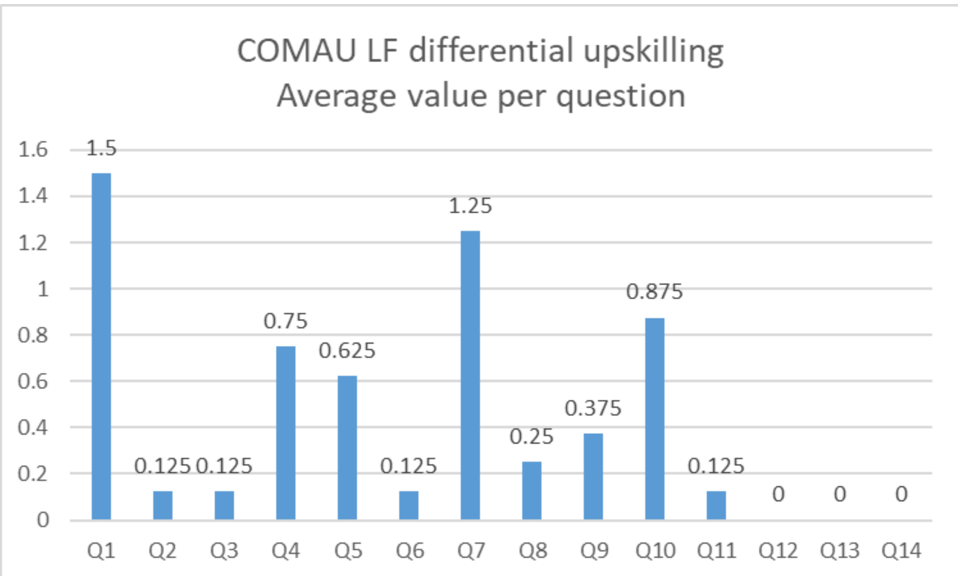

Figure 28: COMAU LF: results for upskilling (Input from trainees, High score is successful upskilling).

Question	Evaluation	Classification	Scale
Q1	Is the current robotic welding system human-centric?	Human Centricity	1-5 Likert scale 1 strongly disagree. 2 disagree. 3 neutral 4 agree. 5 strongly agree
Q2	Is the current robotic welding system sustainable?	Sustainability	
Q3	Is the current robotic welding system resilient?	Resilience	

Table 21: COMAU: final questionnaire used for upskilling (session 3, TF).

The results of these surveys are shown aggregately per pillar in the next section (6.2).

5.5.3.3 Outcomes.

For COMAU, according to the company, regarding semi-automating welding has brought these outcomes:

- Acceptance of technology
- Better procedures of training
- Safety as human centricity
- Better internalisation of sustainability and resilience
- Potential redesign of welding technology to better fit Industry 5.0

It is noted that in terms of specific results, resilience was not easily understood by operators, while the re-design of the welding technology, through integrating additional technologies as well as elaborating on specific workflows as well is highly useful towards achieving full operationalization of Industry 5.0-related solutions.

5.6 TKSE (External case).

5.6.1 Introduction.

Since internal transformations had already started in TK, BRIDGES 5.0 was an opportunity to assess the role of such transformations towards Industry 5.0 adoption. To this end, in December 2024, with the help of TUDO, an intervention took place.

- Format: A total of 8 people took part in the two-hour group discussion and two interviewers [IN1, IN2]. The workshop topics included the assessment and further development of additional qualifications related to hydrogen, as well as the digitalisation of training within the company.
- Informed consents have been gathered from all the participants.

It focused on the two targets of the transformation(s), Hydrogen and digitalisation.

Figure 29: THYSSENKRUPP NUCERA: the apprentices group of the additional qualification hydrogen, visiting the hydrogen electrolyser.

5.6.2 Brief description of training.

Intervention Hydrogen Skills for Green Steel: The additional qualification, Hydrogen Usage (Direct Reduction) in steel production, has now (end of 2024) been running a second time, with a new round of apprentices (selecting the top ten students every year). This programme is now highly successful and institutionalised. Final examinations are conducted externally by the regional chambers; other companies are also using this programme and training.

- Intervention: Shifting to digital and self-determined learning: The apprentices are equipped with tablets and have access to the online learning platform. However, the usage of self-learning programmes remained limited (for students and instructors/teachers). To increase the usage of the learning platform, the modules have been adjusted to reflect the specific working conditions, workplaces, and processes, as well as the formal qualifications of the dual system and the related educational regulations. This led to the consolidation and merging of internal and external training modules. The modernised self-learning modules could, for instance, now be used for preparing the on-the-job training units. However, the trainers and instructors now have a version that is much more reflective of the company training pathways and structures. Not to forget that not only the content and its integration in the previously used training framework, but also a train-the-trainer programme and didactical improvement took place.

1) Additional qualification module Hydrogen

As MA1 explains, the topic is generally of interest due to the company's decarbonisation strategy, which has arisen in the context of corresponding EU regulation. The company plans to commission its first direct reduction plant for steel production in 2027, with a demonstration plant due to go into operation as early as 2025. After initially considering the creation of a new profession working in the new plant, it was then recognised that a variety of professions would be affected by the technical innovation (production, maintenance). For this reason, it was decided to proactively develop an "additional hydrogen qualification" accessible to various training groups.

Initially, many external and internal stakeholders were involved:

- The university at the company's headquarters, or a spin-off institute specialising in fuel cell technology.
- another steel company with a presence in Duisburg,
- the local Chamber of Industry and Commerce, which designs the training occupations and takes the exams in Germany.
- the local vocational education school in Duisburg
- the responsible trade union (IG Metall)
- the employers' liability insurance association
- the management of the company.

Theoretical training for seven trainers at the institute as mentioned earlier formed the basis for the development of the additional qualification. This provided the trainers with the necessary expertise on the topic of hydrogen and also enabled them to develop the additional qualification further. One of the trainers (AU2) reports on this unusual experience:

"We were trained by the [institute], and they are actually more used to working with young students who also want to study physics and chemistry. They also tried to do this with us using their documents. Some of the lessons were really tough."

2) Digitisation

Overall, the digitalisation of training in the company is presented by participants as a qualitative improvement. After digitalisation had been rather fragmented in the past, the introduction of a digital learning platform (VOCANTO) a year and a half ago, along with its subsequent company-related development, marked a significant milestone. In addition, the possibilities of virtual welding, assembling a gearbox via augmented reality, and taking courses via Workday are cited as examples of digitalisation (see below for details).

In addition to the need to relocate training to the home office due to the coronavirus pandemic, another important driving force behind the ongoing systematisation is the adaptation of training measures to the target group needs of trainees, who belong to a younger generation and learn in a unique way:

“We simply have to stay up to date, I say. And I keep realising that today's trainees are simply distinct types of learners from what I was when I was younger” (AU1, para. 38).

"It's also up to us to make training a bit more attractive again. That is such a big issue, the days of just frontal teaching are somehow a bit over” (AU2, para. 41).

This different approach is illustrated in the discussion using a few examples, such as that content to be explained is better understood using an online video than through the trainer's explanation or when digitalised content is preferred to paper materials, as this allows for much more flexible learning in terms of time and location, e.g., on the way home, having a continuously accessible repository of learning solutions.

Digitalisation processes in the area of continuing education often meet with less acceptance, especially among older employees. As AU1 points out, there is often a lack of intuitive understanding of the tools used and their functions. Additionally, a notable discrepancy exists between the generations of employees regarding the exchange of experiences and individual knowledge. As AZ2 explains, older colleagues often have workplace experience that they are sometimes reluctant to pass on to younger colleagues. However, the apprentices stated that there is a growing mutual exchange and learning experience by helping the elder colleagues with the usage of digital tools, and the elder colleagues are supporting the younger ones with their workplace experience.

3) Summary

The company is breaking new ground in both projects (additional qualification hydrogen and digitalisation of training). While it was possible to draw on existing structures that characterise the dual training system in Germany for the development of the additional qualification hydrogen and, above all, the content dimension represents an innovation, there is only limited methodological experience for the digitalisation of training.

Both projects have not yet been finalised. In the case of the additional qualification hydrogen, it is expected that larger target groups will benefit from the content in the future and that it will be expanded with practical elements as soon as the plant opens in 2027. In the case of digitalisation, the available materials and content have yet to be extended and systematised.

5.6.3 Results of the training.

5.6.3.1 Questionnaire.

For completeness, the following table presents the questionnaire used for upskilling.

Question	Evaluation	Classification	Scale
Q1	Do you feel confident in solving problems during the manufacturing process?	Sustainability, Human Centricity	1-5 Likert scale 1 Not at all confident 2 Slightly 3 Neutral 4 Quite confident 5 Very confident
Q2	Do you feel confident in using shared control between human and machine?	Resilience, Human Centricity	
Q3	Do you feel confident in working in different project at the same time?	Resilience, Human Centricity	
Q4	Do you feel confident in working in different working areas in the company?	Resilience, Human Centricity	

Table 22: TKSE: final questionnaire used for upskilling.

5.6.3.2 Survey results.

The results of this survey are shown aggregately per pillar in the next section (6.2). Indicatively, here, the mean values are shown. Interestingly, all four averages are quite high, due to the fact that internal transformations had already had some impact on the trainees.

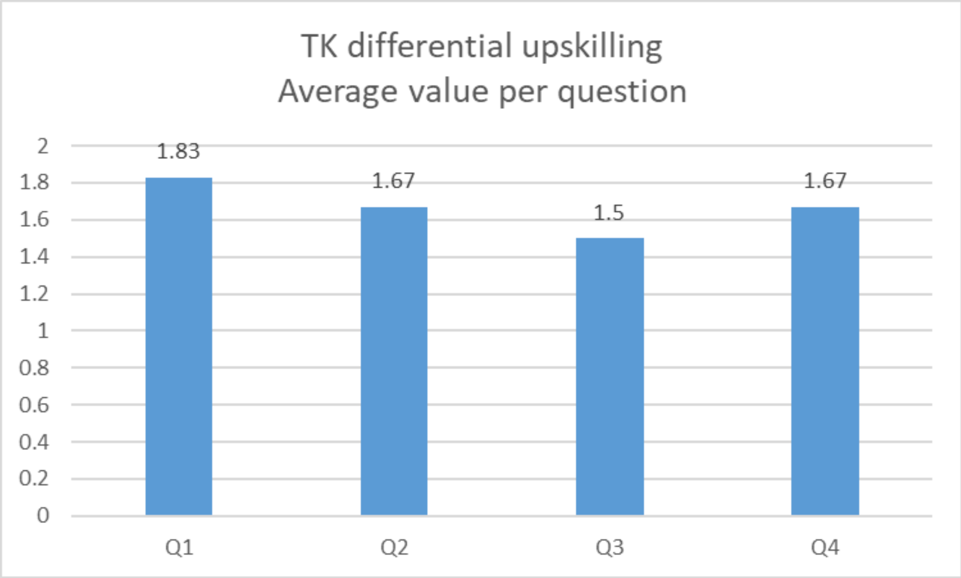

Figure 30: TKSE: results for upskilling (Input from trainees, High score is successful upskilling).

5.6.3.3 Outcomes.

As the goal for TK is the transition to green technology and the adoption of digital technologies, these outcomes can be briefly mentioned, based on the feedback of TK:

- Better and more digitalized workplaces
- Digital and green steel production processes
- Both leading to a better image and better recruitment possibilities.

With respect to more specific outcomes, some additional qualitative aspects follow.

1) Additional qualification module Hydrogen

The two trainees who took part in the programme rate it positively:

- *AZ1: "And I can definitely say that it is very valuable for us in the long term, and I am also happy that I did this additional qualification."*
- *AZ2: "Even though this hydrogen course was only theory-based, I think that you can take a lot with you into practice, and that's why I was delighted with the additional qualification."*

AZ1 does not state in his reasons why he is satisfied/happy with completing the additional qualification, nor why it is something valuable to him, but does provide a time horizon ("long-term"). AZ2 expresses the expectation of being able to transfer a significant amount of knowledge from the course into practice, ultimately improving their work performance.

Conclusion: The additional hydrogen qualification is of significant importance to the company, as it is crucial for the successful decarbonisation of its steel production, and the introduction of a separate profession for the new technology was not considered appropriate.

In line with the comparatively formalised training system in Germany, the additional qualification was developed in cooperation with local stakeholders such as the Chamber of Industry and Commerce, the vocational school, and to a lesser extent also by professional associations and trade unions. The participants described this collaboration as incredibly positive and exciting, even if there were gradations in the quality of the collaboration with individual stakeholders.

According to the manager, the additional qualification of hydrogen is also attracting new talents and growing in interest outside of the steel industry. It is also increasing trainees' career opportunities. At the same time, this opens the risk that trainees who do not obtain this qualification will miss career opportunities. This perceived risk means that broader access to the qualification is a topic that is definitely being intensively discussed in the workshop.

There is still no clearly defined path for the further development of the additional qualification. However, the primary objective appears to be to equip more trainees and employees with knowledge about hydrogen in the future. However, there are concerns that the current additional qualification would be too demanding for many trainees, which is why the discussion is also flirting with the idea of only making certain content available to high-performing trainees. However, to achieve the broad impact that the programme aims to achieve, consideration is also being given to integrating the additional qualification into the regular training for the various professions in future.

2) **Digitisation**

Digitalisation processes in the area of continuing education often meet with less acceptance, especially among older employees. As AU1 points out, there is usually a lack of intuitive understanding of the tools used and their functions. Additionally, a notable discrepancy exists between the generations of employees regarding the exchange of experiences and individual knowledge. As AZ2 explains, older colleagues often have experience that they are sometimes reluctant to share with younger colleagues.

During the discussion, various functions of the platform are mostly emphasised in a positive light. On the one hand, the content provided covers "most training occupations" and is therefore relevant for both commercial and technical occupations. At the same time, the platform also provides an opportunity to bring together existing material and make it usable across locations. This also enables the company to standardise training practices at its locations to a greater extent. To this end, a process is currently underway in which the materials are assigned to the modules of the company's training plan and are thus readily available to the various trainers.

Conclusion: The digitalisation of training in the company appears to have five primary motivations: Firstly, trainees are provided with learning methods that are more in line with their preferences. Secondly, digitalisation opens the possibility of recording, systematising, and standardising learning content within the company and across trainers. Thirdly, the tools provide trainers with additional means to improve their teaching. And fourthly, the digitalisation of materials also offers the opportunity to standardise work processes. The fifth argument is to attract (young) talent in the future.

Digitalised training content is now standard and has become indispensable among trainees. Nevertheless, the workshop also shows that the company is still in a phase of transformation in which separate knowledge is being centralised and is therefore available to a greater extent within the company. A key lesson learned from the initial digital training versions was that the given system needed to be adapted and further developed by the trainers to incorporate specific, relevant content and workplaces within the company. This means a change for the trainers, who must adjust their pedagogy to the new tools and the learning habits of the trainees and may also (must) make less use of their learning materials.

Another critical challenge is the recording of knowledge that has not yet been digitised. In addition to the recording of training materials already in use, this also potentially affects the experience of older employees, which has not yet been systematically recorded. Similarly, for tools such as the augmented reality recording of gearboxes, the underlying technical systems must also be recorded, which is not yet the case for all systems.

Overall, the company appears to be in a situation in which digitalised content already plays a key role in training. Still, there is also enormous potential for integrating further knowledge and content into digitalised training.

5.7 Other external cases (partial interventions).

Several external companies are interested in the TLF5.0. We have been working with them, especially towards future-proofing the interventions.

MORROW BATTERIES, being an existing start-up and currently the most advanced battery producer company in Norway, they are building expertise from scratch. So, results are not yet available.

Also, regarding ATLAS COPCO, the intervention is organised to improve the overall operational performance in the Technical Support. The discussions are continuing and not finalised at the date of this report.

Finally, for the case of AIRBUS, even though they have shown interest, another company is foreseen to be used instead.

As the topics of these cases have not been central to BRDIGES 5.0, all relevant conclusions from the corresponding interventions will be included in D6.4.

6 Phase 4 - Evaluation Results.

6.1 Introduction.

This Section presents the evaluation of the training interventions. The focus is on evaluations by training participants (the degree of upskilling that is achieved) and by the companies (general satisfaction of the intervention; the easiness of the implementation; and a qualitative feedback on three questions: involvement of personnel, involvement of senior management, and need for co-creation).

First, the evaluation per pilot is presented. Statistical and qualitative analyses are presented. Next, the effectiveness of interventions is compared. Lastly, an effort is made to understand if the pilots provide a more general perspective on the type of competences the TLF 5.0 are stimulating within companies.

6.2 Evaluations by training participants and companies.

6.2.1 Mondragon case.

6.2.1.1 Upskilling.

Table 23 summarises the upskilling per pillar, after averaging the differences of all the relevant questions in Section 5.2.3.1 over the two measurement moments. For instance, in the case of Mondragon, Q1 to Q4 contribute to human centricity, Q5 is about Resilience and Q6 & Q7 are related to sustainability. Also, Cohen's d metric is shown in brackets. Thus, the highlighted scores are the significant ones (higher than 0.5 in absolute values as well as higher Cohen's *d* than 0.2).

Intervention	Sustainability	Resilience	Human Centricity
ERREKA TF	0.95 (1.33)	1.75 (3.5)	1.625 (5)
FAGOR TF	0.571 (0.68)	0.851 (0.63)	0.786 (0.65)

Table 23: MONDRAGON Cases: upskilling results per pillar and per training intervention. The scale refers to a differential Likert scale (post–pre). (Input from trainees, High score is successful upskilling, green background means high impact).

The table shows that for all pillars in both companies; we can see that the participants see an improvement.

6.2.1.2 Company transformation.

Figure 31 compares the responses of managers of FAGOR and ERREKA of the training (for questionnaire, see Annexe 4, Part B).

Figure 31: MONDRAGON Cases: company level characterisation (similar results for FAGOR And ERREKA). Feedback from company managers - for questionnaire, see Annexe 4, Part B.

The figure shows a strongly improved evaluation of the human-centricity dimension of the training.

6.2.1.3 Intervention easiness.

Table 24 shows how the two companies evaluate the interventions. Both organisations are neutral about the easiness of implementation, but positive about the upscaling possibilities. The average is higher than the threshold of 3.5 in both cases.

Question	ERREKA	FAGOR
How easy was it to implement the intervention?	3	3
Is the intervention generic enough to be of interest to distinct groups **of trainees?**	5	5
AVERAGE	4 – they agree on the easiness	4 – they agree on the easiness

Table 24: MONDRAGON Cases: characterisation of intervention (1=strongly disagree – 5=strongly agree, Feedback from company managers).

6.2.1.4 Qualitative validation of practices.

The following tables provide management reflections on the role of co-creation in the design and implementation of workplace training practices within two cooperative companies. While both cases were shaped by collaborative environments, they differed in the extent to which workers and managers were directly involved in shaping the interventions. One approach featured more active engagement and iterative feedback, while the other relied primarily on external design informed by initial consultations. In both, the ability to align training with workplace realities and participant needs emerged as a key factor in effective implementation.

Question	ERREKA
How are groups of operators and managers involved in the design/ implementing of the intervention? Are they given time and resources required to enable their active involvement? If they were not involved, please explain why.	Operators are a source of feedback for the instructors who developed the hydrogen qualification – with it, the qualification can be further developed. Workers' representatives (work council, trade union) were informed about the development of the hydrogen qualification.
What aspects would you add to such interventions, so that you achieve targets, such as management structure change?	Besides the continuous improvement of the intervention of the hydrogen qualification, practical showcases will be available in the future. Workers' feedback can be integrated into the design of the qualifications. Also, an adaptation of the contents to different target groups is still on the task list.
	Regarding the digitalisation, more aspects of the real (educational and production) aspects of the company and its workplace conditions must be represented in the digital environment. Instructors and workers need to integrate these resources into their learning and teaching activities
Is senior management really committed to the intervention? How do you know?	Yes. The president of the cooperative company and the industrial manager were on the intervention.
Who are the principal stakeholders (individuals or groups who have been affected by the intervention and/or whose support is necessary for its success)? Have their roles and potential contributions been clearly defined, and if so, how? Are trade unions or employee forum representatives involved as active participants?	Industrial Managers and technicians are involved in digitalisation processes.
	There are no trade unions in the cooperative company. All participants in the interventions were members of the company.
What are the intended outcomes in terms of company performance?	A better adoption (by workers) of the technology implemented
How will the delegation of decision-making affect the existing management structure and management roles?	There is no delegation of decision-making
Have you anticipated potential sources of resistance? What is the best way of dealing with it?	The main resistance is not to engage people with the content of the intervention. Participants have overloaded agendas, and if they feel the intervention is not adding something new, they will not finish it.

Table 25: MONDRAGON Cases: answers by company managers about the training.

Question	FAGOR
How are groups of operators and managers involved in the design/ implementing of the intervention? Are they given time and resources required to enable their active involvement? If they were not involved, please explain why.	They were not involved so much. Mondragon Goi Eskola Politeknikoa made the development after listening to their difficulties.
What aspects would you add to such interventions, so that you achieve targets, such as management structure change?	(As above)
Is senior management really committed to the intervention? How do you know?	People Management manager involved in the definition process (although he did not take part in the intervention)
Who are the principal stakeholders (individuals or groups who have been affected by the intervention and/or whose support is necessary for its success)? Have their roles and potential contributions been clearly defined, and if so, how? Are trade unions or employee forum representatives involved as active participants?	Digitalisation managers and technicians are involved in digitalisation processes. There are no trade unions in the cooperative company. All participants on the interventions were members of the company.
What are the intended outcomes in terms of company performance?	A better adoption (by workers) of the technology implemented, to make the best use of the technology implemented.
How will the delegation of decision-making affect the existing management structure and management roles?	There is no delegation of decision-making
Have you anticipated potential sources of resistance? What is the best way of dealing with it?	The primary resistance is not to engage people with the content of the intervention. Participants have overloaded agendas, and if they feel the intervention is not adding anything new, they will likely not complete it.

Table 26: MONDRAGON Cases: answers by company managers about the training.

6.2.1.5 Conclusion.

The Mondragon companies report a significant improvement in upskilling, as shown above. Additionally, there has been impact at company level (20% increase) in human centricity, corresponding to a level of increase more than 0.125 (in Likert scale), which is the estimated Minimally Important Difference for companies' level, following the methodology of Section 3.3. Last, management perceives the intervention as easy and straightforward. The overall conclusion is that both interventions have been successfully implemented.

6.2.2 Infineon case.

6.2.2.1 Upskilling.

Table 30 shows the improvement of upskilling for the three pillars. Only 'sustainability' shows a significant improvement of upskilling. The questions are those of Section 5.3.3.1.

Intervention	Sustainability	Resilience	Human Centricity
INFINEON TF	0.567 (0.7)	0.1 (0.17)	0.268 (0.536)

Table 27: INFINEON: upskilling results per pillar and per training intervention. The scale refers to a differential Likert scale (post–pre) (Input from trainees, High score is successful upskilling, green background means high impact).

6.2.2.2 Company evaluation.

Figure 32 compares the responses of managers of INFINEON of the training (for questionnaire, see Annexe 4, Part B). All dimensions show improvement. As with Mondragon, the strongest improvement is with human-centricity.

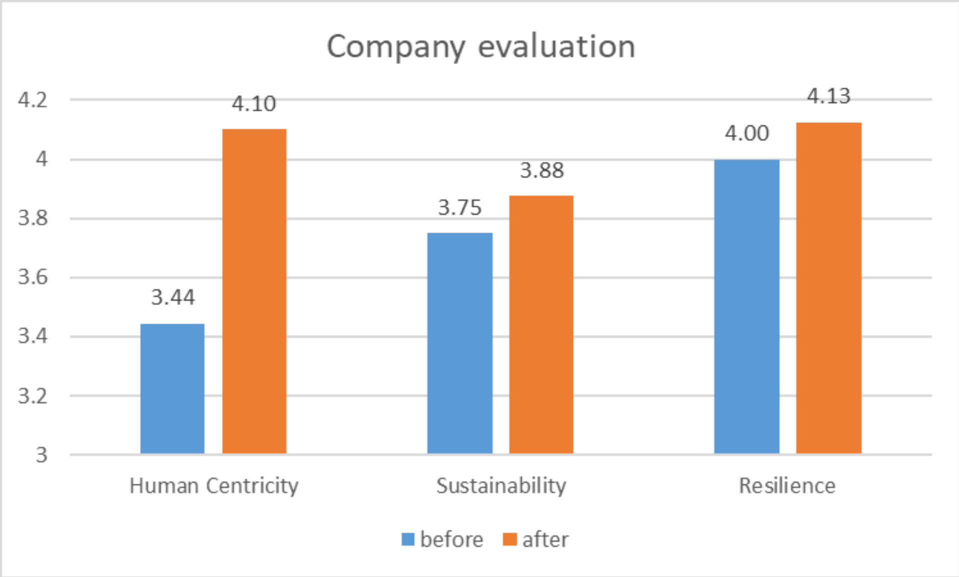

Figure 32: INFINEON: company level characterisation. Feedback from company managers - for questionnaire, see Annexe 4, Part B.

6.2.2.3 Easiness intervention.

Table 31 shows how INFINEON evaluates the interventions. The companies are quite neutral on the easiness of implementation, but positive about the upscaling possibilities. The average is higher than the threshold of 3.5.

Question	INFINEON
How easy was it to implement the intervention?	3.5
Is the intervention generic enough to be of interest to distinct groups **of trainees?**	4
How easy is it to extend the intervention within the company?	3.5
Average	3.67

Table 28: INFINEON: characterisation of intervention (1=strongly disagree – 5=strongly agree, Input from trainees).

6.2.2.4 Qualitative validation of practices.

The following table reflects management feedback on Infineon's training efforts, particularly within the Remote-Operations Control Centre (ROCC). The intervention demonstrates strong organisational support, with structured involvement from line experts, engineers, and technicians in both content development and implementation. Senior management's commitment is evidenced by consistent staffing, training plans, and open communication. The company also recognises the need to overcome resistance through mindset shifts and aims to elevate the role of line experts as key decision-makers within the production ecosystem.

Question	INFINEON
How are groups of operators and managers involved in the design/ implementing of the intervention? Are they given time and resources required to enable their active involvement? If they were not involved, please explain why.	Mixed groups in topic development are particularly good. Time and resources are available.
	The company's advantage is that when new developments arise, we are always professionally trained and informed. The company is trying to conduct training as well as possible, and when it comes to implementation, complications can, of course, arise, but most people are trying to find a solution
What aspects would you add to such interventions, so that you achieve targets, such as management structure change?	Strengthening the position of the Line Expert face-to-face with other areas to enable communication on an equal footing
	To achieve a goal, everyone must participate; one person alone is not enough. Important aspects: Communication, define the goal as clearly as possible. Implementation - how? e.g. through training, preparations, etc.
Is senior management really committed to the intervention? How do you know?	Appropriate training plans, constant staffing of the ROCC workstations, direct open communication and interest in my views are desired and recognised. I know this from working with my direct and superior supervisors.
Who are the principal stakeholders (individuals or groups who have been affected by the intervention and/or whose support is necessary for its success)? Have their roles and potential contributions been clearly defined, and if so, how? Are trade unions or employee forum representatives involved as active participants?	Line experts, process engineers, maintenance technicians -> for the department's internal processes. Line control, automation, and IT for the overall process.
What are the intended outcomes in terms of company performance?	Increased stability in production and efficiency improvement.
How will the delegation of decision-making affect the existing management structure and management roles?	Hopefully, strengthening the role of the line experts
Have you anticipated potential sources of resistance? What is the best way of dealing with it?	Yes. Inflexible behaviour is challenging to overcome, and the necessary "mindset change" for new measures can only be achieved through consistency and clear responsibilities in decisions and responsibilities

Table 29: INFINEON: answers by company managers about the training.

6.2.2.5 Conclusion.

Firstly, INFINEON reports a modest improvement in upskilling. Secondly, there has been impact at company level (19% increase) in sustainability, corresponding to a level of absolute increase more than than 0.125 (in Likert scale), which is the estimated Minimally Important Difference for companies' level, following the methodology of Section 3.3. Also, management perceives the intervention as easy and straightforward. The overall conclusion is that both interventions have been successfully implemented.

6.2.3 Kitron case.

6.2.3.1 Upskilling.

Table 30 shows that for all pillars, participants at KITRON see an improvement. The corresponding questions are those of Section 5.4.3.1.

Intervention	Sustainability	Resilience	Human Centricity
KITRON TF	1.21 (1.5)	1.45 (1.85)	1.23 (1.86)

Table 30: KITRON: upskilling results per pillar and per training intervention. The scale refers to a differential Likert scale (post–pre) (Input from trainees, High score is successful upskilling, green background means high impact)

6.2.3.2 Company evaluation.

Figure 33 compares the responses of managers of KITRON of the training (for questionnaire, see Annexe 4, Part B). Here, the increase is smaller than in the previous cases.

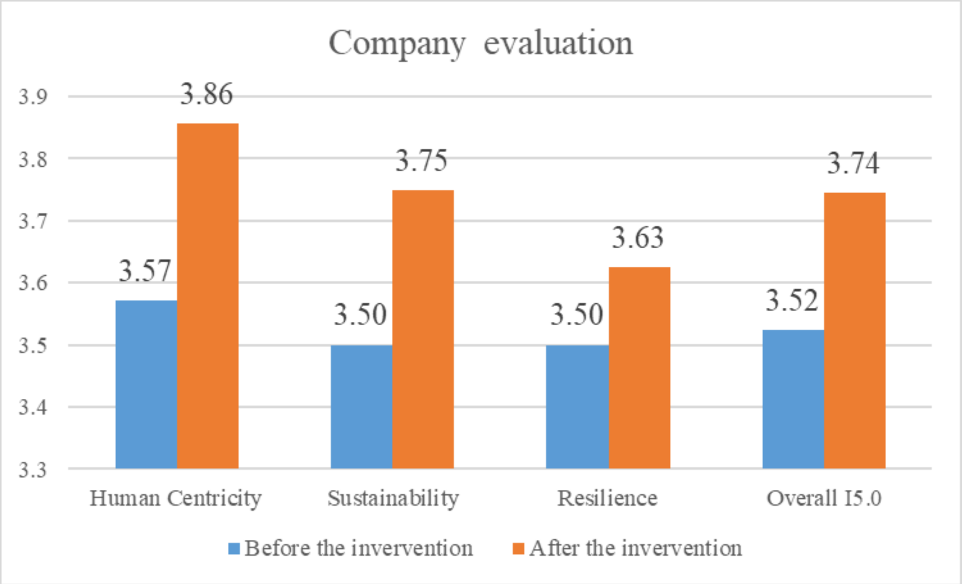

Figure 33: KITRON: company level characterisation. Feedback from company managers - for questionnaire, see Annexe 4, Part B.

6.2.3.3 Intervention easiness.

Table 31 shows how KITRON evaluates the intervention. Managers are positive about the easiness of implementation and the upscaling possibilities. The average is higher than the threshold of 3.5.

Question	KITRON
How easy was it to implement the intervention?	4
Is the intervention generic enough to be of interest to distinct groups **of trainees?**	4
How easy is it to extend the intervention within the company?	4
Average	4

Table 31: KITRON: characterisation of intervention (1=strongly disagree – 5=strongly agree, Feedback from company managers).

6.2.3.4 Qualitative validation of practices.

The following table reflects management insights on the Kitron intervention, which was shaped through the collaboration of multiple departments and direct input from new operators. While senior management engagement was selective, key figures like the Quality Manager were involved.

Question	KITRON
How are groups of operators and managers involved in the design/ implementing of the intervention? Are they given time and resources required to enable their active involvement? If they were not involved, please explain why.	Different related departments (employees, managers) participated in the design of this intervention to seek a better and targeted result. New operators/employees participated in this intervention directly by testing new training methods/approaches and providing feedback for improvement.
What aspects would you add to such interventions, so that you achieve targets, such as management structure change?	Involvement of different related departments and stakeholders is part of such an intervention's success. Also applying best practices from other cases/companies.
Is senior management really committed to the intervention? How do you know?	Part of senior management is committed to the intervention (e.g., the Quality manager is participating in the project), however, not to the full extent.
Who are the principal stakeholders (individuals or groups who have been affected by the intervention and/or whose support is necessary for its success)? Have their roles and potential contributions been clearly defined, and if so, how? Are trade unions or employee forum representatives involved as active participants?	Stakeholders are the Quality department (Training branch included) and the Manufacturing department. Trade unions or employee forum representatives are not actively involved.
What are the intended outcomes in terms of company performance?	Increase in standard efficiency, number of employees available to shift in different work centres, KPI/Recycling audit result (before and after process change), energy cost per employee efficiency
How will the delegation of decision-making affect the existing management structure and management roles?	Management structure was not affected at all
Have you anticipated potential sources of resistance? What is the best way of dealing with it?	Resistance is mainly coming from manufacturing employees, as they currently do not see the full picture and do not envision long-term results and benefits for themselves. Therefore, we are trying to simply explain and educate them on how the intervention works and what the possible benefits are.

Table 32: KITRON: answers by company managers about the training.

6.2.3.5 Conclusion.

KITRON reports a modest improvement in upskilling, as per above. Also, there has been impact at company level (8% increase) in human centricity, greater than 0.125 (in Likert scale), which is the estimated Minimally Important Difference for companies' level, according to the methodology of Section 3.3. Finally, management perceives the intervention as easy and straightforward. The overall conclusion is that both interventions have been successfully implemented.

6.2.4 Comau case.

6.2.4.1 Upskilling.

For the case of Comau, due to the fact that the intervention is technology-centric, in upskilling estimation, Q1, Q7, Q10, Q11 and Q12 were used. Thus, Table 33 summarizes the upskilling per pillar, after averaging the differences of the aforementioned questions, which can be found in Section 5.5.3.1.

Intervention	Sustainability	Resilience	Human Centricity
Comau training	0.207 (0.296)	0.27 (0.45)	0.22 (0.44)
Comau LF	1.397 (2.26)	1.375 (1.34)	0.816 (1.37)
Comau TF	0.533 (0.88)	0.467 (0.58)	0.433 (0.96)

Table 33: COMAU: upskilling results per pillar and per training intervention. The scale refers to a differential Likert scale (post–pre). (Input from trainees, High score is successful upskilling, green background means high impact).

Even when upskilling is recalculated using the full set of questions relevant to each pillar, the Learning Factory (LF) still demonstrates strong results in Human-Centricity. Specifically, the average post-pre score across questions Q5 to Q8 is 0.6, with a corresponding Cohen's *d* effect size of 1.1, indicating a large and meaningful learning impact.

6.2.4.2 Company evaluation.

Figure 34 shows the company-level evaluation of the various practices. The improvement of the scores has been limited, but the starting situation was already positive for human centricity and resilience.

Figure 34: COMAU: company level characterisation. Feedback from company managers - for questionnaire, see Annexe 4, Part B.

6.2.4.3 Intervention easiness.

Table 34 summarises the characterisation of the intervention itself, once again in a Likert scale. Easiness has been evaluated as quite positive. The average is higher than the threshold of 3.5.

Question	COMAU
How easy was it to implement the intervention?	5
Is the intervention generic enough to be of interest to distinct groups **of trainees?**	4
How easy is it to extend the intervention within the company?	5
Average	4.67

Table 34: COMAU: characterisation of intervention (1=strongly disagree – 5=strongly agree, Feedback from company managers).

6.2.4.4 Qualitative validation of practices.

The management feedback table below highlights COMAU's clear commitment to human-robot collaboration as a strategic solution. Senior leadership strongly endorsed the intervention, which focuses on improving quality and reducing physical strain for operators. The main stakeholders involved (shipbuilders and integrators) are central to implementation. Anticipated resistance relates to shifting from flexible manual routines to more structured robotic processes, which management aims to overcome by emphasizing both performance and ergonomic gains.

Question	COMAU
Is senior management really committed to the intervention? How do you know?	Senior management strongly pushes towards this solution.
Who are the principal stakeholders (individuals or groups who have been affected by the intervention and/or whose support is necessary for its success)? Have their roles and potential contributions been clearly defined, and if so, how? Are trade unions or employee forum representatives involved as active participants?	Shipbuilders and integrators. There were no issues coming from trade union or employee forum representatives.
What are the intended outcomes in terms of company performance?	Higher quality, accuracy, and performance.
How will the delegation of decision-making affect the existing management structure and management roles?	-
Have you anticipated potential sources of resistance? What is the best way of dealing with it?	The "old way" may be more flexible to the different specific situations, but the idea is to show the benefits for both the results and the health of the workers (it substitutes the workers in effortful physical tasks)

Table 35: COMAU: answers by company managers about the training.

6.2.4.5 Conclusion.

COMAU reports a modest improvement in upskilling with the TF and a strong improvement with the LF regardless of the estimation. However, the first training intervention has not brought the desired extent, with Cohen's *d* criterion being small. We will, however, take advantage of it, further below. There has been impact at company level (5% increase) in overall metric. This is larger than 0.125 (in Likert scale), which is the estimated Minimally

Important Difference for companies' level, according to the methodology of Section 3.3. Moreover, management perceives the intervention as easy and straightforward. The overall conclusion is that both interventions (TF & LF) have been successfully implemented, even if improvements are possible.

6.2.5 TK case.

6.2.5.1 Upskilling.

Table 36 summarises the upskilling per pillar for the case of TK, after averaging the differences of all the relevant questions in the questionnaire of Section 5.6.3.1. Also, Cohen's d metric is shown in brackets. Thus, the highlighted scores are the significant ones (higher than 0.5 in absolute values as well as higher Cohen's *d* than 0.2).

Intervention	Sustainability	Resilience	Human Centricity
TKSE TF	1.83 (2.4)	1.4 (1.6)	1.67 (2)

Table 36: TKSE: upskilling results per pillar and per training intervention. The scale refers to a differential Likert scale (post–pre). (Input from trainees, High score is successful upskilling, green background means high impact).

6.2.5.2 Intervention easiness.

Table 37 summarises the characterisation of the intervention itself, once again in a Likert scale. The evaluation is positive, and the average is higher than the threshold of 3.5.

Question	TK
How easy was it to implement the intervention?	4
Is the intervention generic enough to be of interest to distinct groups **of trainees?**	5
How easy is it to extend the intervention within the company?	4
Average	4.67

Table 37: TKSE: characterisation of intervention (1=strongly disagree – 5=strongly agree, Feedback from company managers).

6.2.5.3 Qualitative validation of practices.

The following table summarises TKSE management's perspective on a training intervention. Senior leadership's investment in modern technologies underscores strategic commitment, while generational differences in digital tool adoption remain the primary cultural challenge. The intervention also anticipates evolving roles for managers and trainers as coaches and enablers within this green transformation.

Question	TKSE
How are groups of operators and managers involved in the design/ implementing of the intervention? Are they given time and resources required to enable their active involvement? If they were not involved, please explain why.	Due to the co-determination model of the steel industry, there is a direct involvement of the workers' representatives at distinct levels and the workers at the workplace
What aspects would you add to such interventions, so that you achieve targets, such as management structure change?	Continuous evaluation and monitoring of the implementation process
	Integration of the workplace experience of the workers and (line) managers
Is senior management really committed to the intervention? How do you know?	Yes, especially concerning the DRI hydrogen production process.
	Regarding self-determined learning and the use of tablets, this is also the case, due to the investment in this technology and the tablets themselves.
	Modern technologies, digitalisation, and decarbonisation are not only relevant for competitiveness, but also for changing the image, delivering green steel, and attracting talented people.
Who are the principal stakeholders (individuals or groups who have been affected by the intervention and/or whose support is necessary for its success)? Have their roles and potential contributions been clearly defined, and if so, how? Are trade unions or employee forum representatives involved as active participants?	Workers and their line/shift managers
	New apprentices
	Workers' councils and representatives are engaged on several levels (management, shopfloor)
	Due to the codetermination model/agreement, the unions are integrated in the decision-making processes
What are the intended outcomes in terms of company performance?	New decarbonised production processes leading to green steel.
	More operator integration for decentralised decision making and self-determined learning.
	New role for trainers as enablers, coaches
How will the delegation of decision-making affect the existing management structure and management roles?	More and better data, in-time information at the workplace
	Managers as trainers and coaches, supervisors
Have you anticipated potential sources of resistance? What is the best way of dealing with it?	No resistance, but the acceptance and usage depend on the individual person in case of the additional qualification of hydrogen. It is a personal choice of the selected apprentice leading to 28 complete education and training days on top of their regular VET. There is a little resistance among some older instructors to using IT Tools for their technical training. They used to train apprentices in person for many years.

Table 38: TKSE: answers by company managers about the training.

6.2.5.4 Conclusion.

TK reports a strong improvement in upskilling. Also, the characterisation at company level after the intervention is good and equal to 4.2[5]. Additionally, the intervention is seen as easy and straightforward. One can conclude that the intervention has been successful. The concept of partial intervention can be used here[6], since we do not have data for the situation before, as the internal transformation had already started.

6.3 Comparison of methods and effectiveness.

The overall Industry 5.0 metric (pertaining to upskilling) is also defined as the mean value of all the questions (from the trainees). Table 39 presents the results of this metric related to upskilling, for all the cases. Two characterisations are included; one based on the absolute values of the metric and one pertaining to Cohen's *d*.

Intervention	Industry 5.0 overall metric	Verbal Characterization based on Cohen's *d*
Comau training	0.207	Small (0.27)
Comau LF	0.938	Large (2.56)
Comau TF	0.633	Large (1.93)
ERREKA TF	1.45	Extremely Large (3.26)
FAGOR TF	0.735	Large (0.75)
INFINEON TF	0.357	Medium (0.6)
KITRON TF	1.359	Large (1.99)
TK TF	2.13	Extremely Large (6.17)

Table 39: Upskilling results for Industry 5.0 overall metric and per training intervention. The scale refers to a differential Likert scale (post–pre). The heat-map used is straight forward: the darker the colour, the larger the value. The verbal characterisation is based on literature (Madsen, 2016). (Input from trainees, the higher score the more successful the upskilling).

Once again, we can verify the success of each case based on overall Industry 5.0 metrics for upskilling. However, two cases have to be pointed out:

- Infineon results for the overall metric are relatively low, probably due to the complexity of the TF and not including the solution elaboration in the stages. It is noted that in this case Cohen's *d* is not small, so the results can be accepted.
- COMAU's first training, on the other hand, has not been a "pure" LF. As such, this can be the basis so that every other intervention is controlled against it.

Next, putting every intervention together and fusing the results, we try to generalise and respond to whether the Industry 5.0 integration is feasible (successful) for everyone, in terms of upskilling. The following forest plot illustrates the outcomes of a meta-analysis (Balduzzi, 2019; Viechtbauer, 2010) performed across multiple training interventions from different

[5] No data prior to the intervention, as the transformation had begun and we did not want to introduce bias.

[6] founded in publication of BRIDGES 5.0 conference in Leuven

companies and instructional formats (e.g., traditional learning, LF, TF). Each row represents the mean effectiveness score (post-intervention minus pre-intervention), along with its corresponding standard deviation and confidence interval. Since the studies follow a pre-post design without control groups, the mean values themselves serve as the effect sizes. A metric that considers all the relevant upskilling-focused questions in terms of an average has been used to this end.

Given the high heterogeneity (I^2 = 93.3%, which represents the percentage due to intrinsic heterogeneity), the random-effects model is preferred for interpretation. The resulting overall effect estimate under the random model is 0.99 [95% CI: 0.51, 1.46], with a prediction interval ranging from -0.66 to 2.63. **The overall effect is satisfactory, since it close to 1 Likert degree, so the set of interventions within BRIDGES 5.0 have been useful with respect to providing guidelines.**

The prediction interval could be interpreted as suggesting that careful design and customised solutions should be regarded in future interventions, **as solutions and trainings are quite case-dependent.**

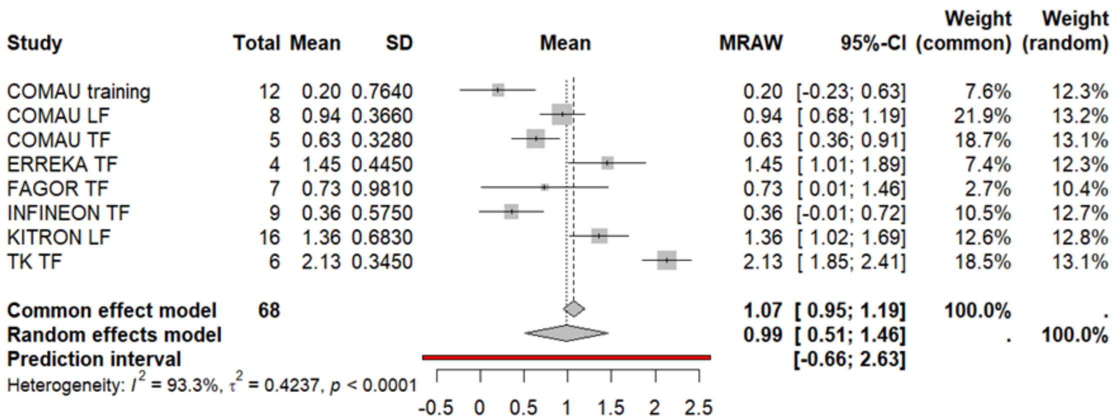

Figure 35: Forest plot for the overall Industry 5.0 metric along cases and statistical fusion. Elaborated result on upskilling result (Input from trainees, High score is successful upksilling)

To elaborate on the effectiveness of the methods in a comparative way and quantify the impact to a larger extent, we take advantage of the fact that the first COMAU intervention was not that successful in terms of upskilling, mainly due to the fact that the experiential (LF-related) part did not focus on the three pillars, but rather on the technology itself. Only presentation-based training was used for the Industry 5.0 concepts. As such, we may now have a metric of what can be considered “traditional learning”. So, we can run a series of meta-analyses, where this traditional learning is used as a control of effectiveness.

Thus, to assess the effectiveness of different training methods within the framework of Industry 5.0, a network meta-regression was conducted, elaborating the concept of controlling effectiveness. The dependent variable in this model was the standardised effect size reflecting training impact across studies. The model included four binary (dummy-coded) independent variables, representing key characteristics of the training interventions.

- TF (Teaching Factory): coded as 1 when the intervention was implemented in a teaching factory context – typically characterised by collaboration between academia and industry, with a focus on real-world production scenarios.
- LF (Learning Factory): coded as 1 when the intervention took place in a learning factory environment – usually emphasising hands-on experiential learning in simulated or semi-real production setups.

- psych: coded as 1 when the intervention included behavioural or psychological components, such as reflective learning, motivational aspects, or mindset development.
-

Company	TF variable	LF variable	psych
COMAU training	0	0	0
COMAU LF	0	1	0
COMAU TF	1	0	0
ERREKA TF	1	0	1
FAGOR TF	1	0	1
INFINEON TF	1	0	0
KITRON TF	0	1	0
TK TF	1	0	1

Table 40: Moderators (independent variables) used in meta-regression and their values per intervention. 1 is existence of characteristic, 0 is absence.

It is noted that the size of the intervention is not a relevant factor. However, these variables were modelled to investigate which configurations are associated with greater training efficacy. The model allowed us to isolate and evaluate the contribution of each approach while accounting for variability across studies.

Factor	Estimate	Confidence Interval Lower Limit
intercept	0.2	<0
TF	0.37	<0
LF	0.83	<0
psych	0.92	>0 (marginally)

Table 41: Coefficients (estimates) used in meta-regression and their values.

To validate the added value of experiential learning in Industry 5.0-aligned training environments, a meta-analytical approach was also employed (Balduzzi et al., 2023). Despite the heterogeneity of the individual studies, they were structured into a connected network of comparisons, as shown in the diagram. Here, various training settings – including Teaching Factories (TF), Learning Factories (LF), and digital/experiential methods like training (traditional) – were treated as interventions to enable indirect and direct comparisons. Although these studies are based on different case scenarios and organisations, they are modelled as comparable using standardised effect sizes. This approach enables the aggregation of evidence on learning effectiveness across diverse implementations, providing a systematic way to assess whether experiential modalities offer a significant advantage over other formats. The network setup (Figure 36 left) thus ensures that even in the absence of traditional control groups, the interconnected structure supports valid inference and the exploration of consistent patterns.

Next, to evaluate the overall effectiveness of experiential learning methods, the various interventions were grouped according to their methodological framework and compared against a standard reference category, namely the traditional learning approach. As illustrated in the second network diagram (Figure 36 right), multiple studies provided comparisons to the reference, with two studies comparing LF to traditional training and five studies comparing TF to traditional training.

The corresponding forest plot summarises the meta-analytic findings, indicating a mean difference (MD) of 0.94 [95% CI: 0.14, 1.73] for LF and 0.82 [95% CI: 0.28, 1.36] for TF relative to traditional training.

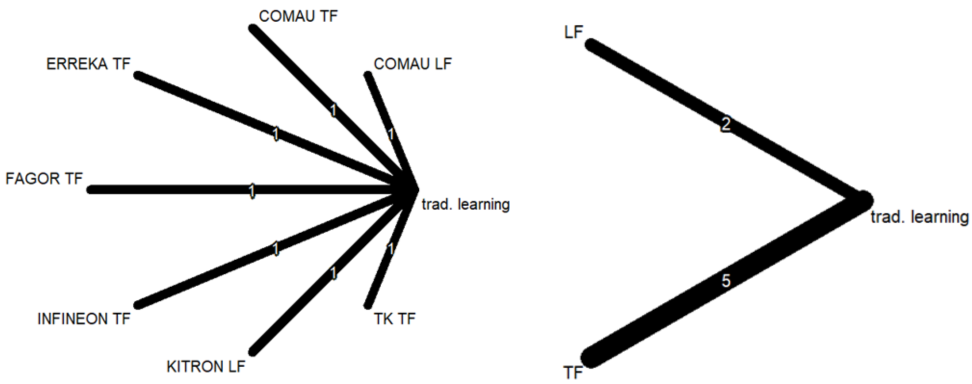

Figure 36: Network graphs used in network meta-analysis: Comparing everything to traditional learning in terms of a one 7-arm study (left) and a grouping (right).

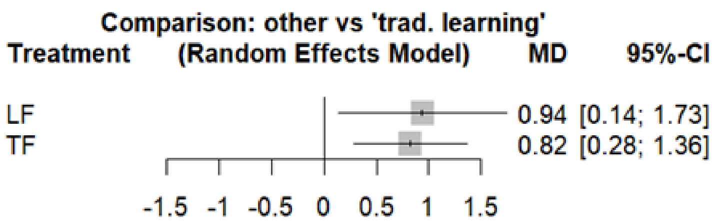

Figure 37: Network meta-analysis results: Impact of LF and TF compared to traditional learning. Elaborated results from trainees' upskilling, high score is successful upskilling.

These statistically significant results suggest that both LF 5.0 and TF 5.0 formats yield superior upskilling outcomes compared to traditional training interventions. This provides robust evidence supporting the integration of experiential learning models in Industry 5.0-aligned training strategies.

6.4 Competences 5.0 extraction.

Our last question is if we can derive an interpretation of what 'Competences 5.0' are in practice. As described in Section 3, the latent structure in the upskilling results per organisation is investigated. This analysis provides which skills dimensions are underlying the answers. It is noted that the use of PCA in a Likert scale is justified, as Criteria for using PCA in various cases were used, namely either Barlett or KMO (Shreshta, 2021). From the list of dimensions, we conduct a content analysis to identify which dimensions of Competences 5.0 seem to be suggested by the answers. These results can be included in future skills research.

6.4.1 Company results.

For **Comau**, the table summarises the competences. It also includes the engaged questions, as well as their loadings (engagement of questions in the Principal Components - PC).

Original question	PC 1 engagement	PC 2 engagement	PC 3 engagement
Awareness	low		
Impact on physical work		high	
Perceived quality improvement		high	
Feeling prepared for change	medium	low	
Anticipated role change	high		
Training importance			
Perceived adaptability	medium	low	
Job satisfaction through tech	medium		
Energy efficiency			high
Material waste			high
Safety			low
Maintainability			high
Continuity			High
Competence name	Self-efficacy & Openness to Technological Change	Positive Perceptions & Value Attribution	Sustainability & Efficiency Awareness

Table 42: COMAU: fuzzy (qualitative) engagement of principal components in the case of COMAU and the respective naming of the emerged competences.

For **ERREKA**, one component was identified. It could be called "**Human-Centric Transformation Readiness**" and aggregates:

- Strategic understanding
- Operational capability
- And negatively loads on the understanding of disengagement.

For **FAGOR**, two components were identified. The first component can be named as **Human-Centric Knowledge & Organisational Readiness**, as it appears to have strong loadings on:

- Disengagement causes
- Human-centric criteria and practices
- Tech implementation knowledge
- Integration of human-centricity with performance

Regarding the second component, its name is **Confidence in Sustainable Optimisation**, aggregating:

- Reducing waste
- Environmental sustainability via optimisation

For the case of **Infineon**, the first component, "**Operational Confidence**" is assembled:

- Problem-solving
- Shared control
- Project multitasking

At the same time, Component 2 ("**Decision Empowerment**") aggregates:

- Solving problems
- project multitasking

Three components are observed in the **Kitron** case, with the first one being **Company Standards & Procedures** that summarise:

- Company principles
- Lean methodology
- Security standards
- Production documentation
- ERP use
- Communication.

The second Component can be **Process & Safety Control**:

- ESD safety
- Hazardous waste sorting
- Component orientation
- MES use

Component 3 is about **Adaptability and Practical Skills**:

- General waste sorting
- Working across different areas
- Communication

Finally, regarding **TK**, the component reflects a broad sense of functional readiness and cognitive flexibility, including:

- Problem-solving
- Human-machine collaboration
- Multitasking/project switching.

These three cluster very tightly, suggesting a cohesive latent competence, named "**Adaptive Operational Readiness**."

It is highly interesting that these competences were not identified in the first place, they were isolated through post-processing of the upskilling results.

6.4.2 Common core.

These twelve 'dimensions' can be summarised into four major clusters of competences.

Cognitive-Affective Readiness for Change (Human-Centric Pillar)

These involve attitudes, beliefs, and motivations that enable individuals to engage with transformation processes:

- Self-efficacy & Openness to Technological Change
- Belief in one’s ability to learn and adapt, openness to innovation.
- Human-Centric Transformation Readiness
- Willingness to engage with changes aligned to human values and dignity.
- Positive Perceptions & Value Attribution
- Internalising the benefits and personal/collective value of the transformation.
- Decision Empowerment
- Readiness to make autonomous decisions; feeling trusted and competent.

Practical and Adaptive Competence (Resilience Pillar)

Focus on skills and behaviours supporting flexible, real-time responses to operational change:

- Adaptability and Practical Skills
- Hands-on capability to adjust to new tools/processes.
- Operational Confidence
- Assurance in one’s ability to function effectively in dynamic settings.
- Adaptive Operational Readiness
- Proactive preparedness to adjust operations in response to challenges.

Organisational Embedding & Structural Alignment

Competences tied to internal structures, norms, and procedural clarity:

- Human-Centric Knowledge & Organisational Readiness
- Alignment of knowledge and systems with I5.0 principles.
- Company Standards & Procedures
- Understanding and adherence to formal structures and protocols.
- Process & Safety Control
- Awareness of regulatory and procedural oversight, especially in high-risk environments.

Sustainability Orientation & Ecological Literacy (Sustainability Pillar)

Attitudes and capabilities focused on environmental awareness and efficiency:

- Sustainability & Efficiency Awareness
- Consciousness of ecological impact and resource optimisation.
- Confidence in Sustainable Optimisation
- Belief in one's ability to implement sustainable solutions effectively.

7 Outcomes and future outlook.

7.1 Implementation of Training Factory 5.0.

WP5 is structured around six technical objectives, which have guided its implementation and evaluation. Hereafter, the way WP5 addressed these objectives is summarised. For each objective, the corresponding outcomes of the work conducted within WP5 are presented.

- *O1: (MAIN objective) - To integrate I5.0 (pillars) in training systems, primarily through TLFs.*

This objective was successfully met, as demonstrated by the outcomes evaluated in Section 6 across three key dimensions: upskilling of participants, company engagement, and the effectiveness of the implemented interventions. The integration of human-centricity, sustainability, and resilience into training processes was evident in all pilot cases. Furthermore, the use of the developed framework and accompanying templates was validated in practice, supporting both the design and execution of TLF5.0 interventions.

- *O2: (PRIMARY objective) - To check skills for I5.0 and Review attitudes.*

This objective was addressed by identifying a set of competences relevant to Industry 5.0, including several that were previously latent or under-recognised. As detailed in Section 6, Principal Components Analysis (PCA) was used to extract and structure these competences, offering a clearer picture of both technical and transversal capabilities within the workforce.

In terms of attitudes, participant responses during evaluation revealed generally positive dispositions toward the training interventions. Trainees demonstrated openness to new learning formats and alignment with Industry 5.0 values, particularly in relation to adaptability, collaboration, and sustainability awareness.

- *O3 (PRIMARY) - To couple business and learning ecosystem aspects and training in job transition.*

This objective was addressed by embedding the training interventions within the broader organisational and learning ecosystems of each company. As highlighted in Sections 4, 5 and 6, work systems and interdepartmental cooperation played a central role in both the design and implementation of the pilots. In several cases, the interventions also aimed to shift organisational mentality – encouraging more collaborative, reflective, and future-oriented workplace cultures – which proved to be a significant enabler for successful job transitions aligned with Industry 5.0 principles.

Also, the facts that COMAU academy enhanced their training portfolio, INFINEON developed classes and KITRON used the help Hybrid Labs, proves the significance of the learning ecosystems.

- *O4: (secondary) - To study organisational and social topics.*

This objective was addressed through close attention to the organisational context in which the training interventions were deployed. Effective communication – both among coworkers and across departments – emerged as a key factor in the success of the pilots. Additionally, companies' willingness to provide opportunities for skill development, particularly through collaborative and experiential learning formats, was recognised as a crucial social enabler for embedding Industry 5.0 principles into workplace culture.

- *O5: (secondary) - To consider humans (trainees) in the co-designing environment.*

This objective was addressed through qualitative evaluation of each pilot, particularly in the sections on "qualitative validation of practices". Feedback consistently indicated that when trainees were actively involved in the design or adaptation of the intervention, outcomes improved significantly. For example, in the COMAU case, co-design contributed to high-impact results, particularly in the redesign of training processes as well as in the redesign of the technology. In the INFINEON pilot, strong participant engagement was reflected in high levels of satisfaction. These findings confirm that involving trainees meaningfully in the intervention process enhances both effectiveness and acceptance.

- *O6: (secondary) - To study aspects of future generalised interventions and extract respective practices for companies.*

A key aspect of this objective was to assess the potential for transferability and scalability of the interventions. The pilots demonstrated that core components – such as modular training design, real-work integration, co-design with trainees, and evaluation tools – can be adapted across diverse sectors and organisational settings. Their success was not context-dependent but stemmed from a flexible methodology that accommodates local needs while preserving alignment with Industry 5.0 principles, with the help of the used templates for design and evaluation. This adaptability positions the TLF5.0 approach as a viable model for broader application across different companies, regions, and industrial ecosystems.

In terms of practical guidance, a preliminary set of actionable practices has been compiled – based both on qualitative feedback from pilots and on targeted brainstorming sessions. These include co-design with trainees, focused training aligned with workplace, and the integration of enabling technologies. A consolidated summary of practices and corresponding template recommendations will be provided in Deliverable D6.3, incorporating findings from ongoing workshops and project outcomes.

7.2 Strategic outcomes.

A key strategic outcome of WP5 is the establishment of structured learning trajectories and training pathways, embodied in the TLF5.0, which are aligned with the principles of Industry 5.0, as envisaged by BRIDGES 5.0. Across all pilot cases, interventions were designed not as isolated training events, but as part of broader developmental pathways within each organisation. These trajectories integrated technical and transversal competences, built progressively through phases of co-design, implementation, and evaluation.

The TLF5.0 approach enabled companies to link workplace practices with learning objectives, embedding training into daily operations and strategic development. This alignment created meaningful opportunities for upskilling, while also fostering long-term capacity-building. In some cases, the pilots led to the institutionalisation of new training formats or services, showing that learning pathways can evolve into sustained organisational routines.

More broadly, the experience of WP5 demonstrates that training pathways developed through TLFs can serve as a mechanism for continuous learning, adaptive workforce development, and integration of human-centric, sustainable, and resilient practices into company culture.

These outcomes affirm that the effort invested in TLF5.0 interventions was both meaningful and impactful. Beyond short-term training gains, the approach enabled companies to embed future-oriented workflows into their organisational routines, strengthen employee engagement, and build capacity for continuous learning. TLF5.0 delivers not just training – it delivers a strategic pathway for companies to transition toward Industry 5.0 by combining technological readiness with human-centric development. This positions the TLF5.0 model as a valuable lever for industrial transformation, adaptable to diverse settings and scalable across sectors. These outcomes present a concrete base for informing EU-level policy and a set of recommendations is documented in D5.2.

In short, we can say that the implementation of TLF5.0 demonstrated not only technical feasibility but also significant organisational benefits. All pilots reported improvements in upskilling, internal coordination, and human-centric innovation capacity, validating the overall value of the effort, with easy, as characterised, interventions.

7.3Limitations and future work.

This study is based on five pilot cases, which naturally limits its generalisability. However, in this study, the close, in-depth engagement with each company yielded rich insights that are often lacking in large-scale, survey-based approaches. While more cases would further validate the model, the current evidence is sufficient to demonstrate the feasibility and added value of TLF5.0, as indicated by the meta-analysis in section 6.

As such, future research should explore how Industry 5.0 competences can be embedded in wider vocational education and training systems. There is also a need to investigate the long-term effects of TLF5.0 on company performance and employee development. Strengthening the evidence base will require additional pilots, preferably across varied sectors and countries, along with longitudinal data collection.

The relevance of Industry 5.0 as a policy and research domain is confirmed by this study. However, to upscale these outcomes, future efforts should focus on creating accessible toolkits, sector-specific templates, and stronger policy alignment mechanisms that enable broad adoption of the TLF5.0 framework at regional, national, and EU levels.

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Annexe 1 – The perspective of businesses.

A training intervention will not affect just the jobs. As foreseen in the template matrix and also pointed out in D1.1, the focus on change management will have repercussions for the companies themselves. As a result, specific company practices will be involved. During WP5, an attempt will be made to identify some of these practices. Additionally, the interpretation of directions into more concrete elements will be drafted. The linking aspect refers to the behaviour of both employees and the company (van Oudenhoven et al., 2023). These procedures will also facilitate the standardisation procedures for further I5.0-related characterisation.

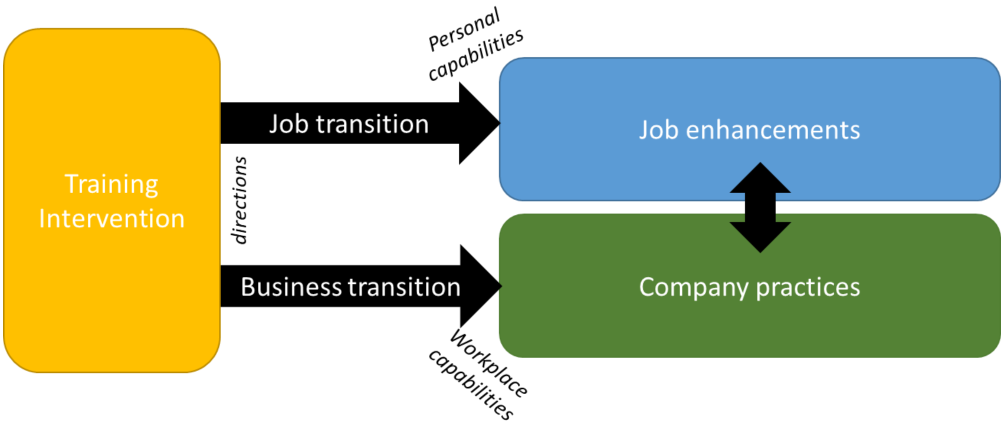

Figure 38: Job and Business transitions as complementary aspects.

The practices are not mentioned in this version of the deliverable, as they exceed their purposes. However, it is noted that, ideally, reference statuses and/or values for identifying assessing the outcome of an transition or an intervention is required (Figure 39). This is the case for both jobs (i.e. upskilling-based evaluation) and companies (i.e. presence of practices and/or KPIs). As both WP5 and WP6 can be field experiments (Bhattacherjee (2019), aiming at checking the feasibility of integrating Industry 5.0 in training in a specific manner, there will be opportunities to isolate indicative samples of the aforementioned references and practices.

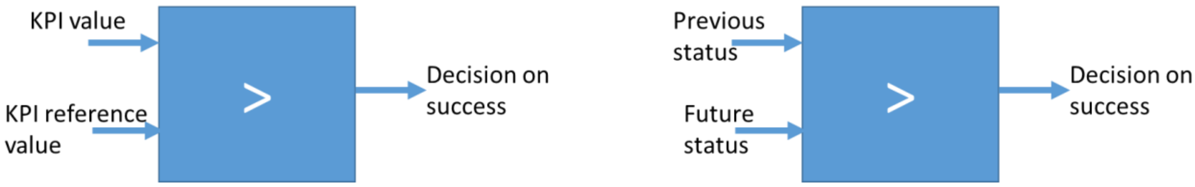

Figure 39: Potential assessments of the outcome of an intervention: Absolute (left) & Relative (right). Such procedures can refer to either training interventions or company transitions. Also, they can be based on KPIs (quantitative) or on questionnaires (qualitative).

Annexe 2 – Heuristic examples of Template matrix elements.

Through the template matrix, it is possible to fill in the definition of the interventions. The following variables could be incorporated. This is a non-exhaustive list, which will be updated in the future.

- I5.0 sustainability KPIs: Energy consumption, CO2 emissions,
- I5.0 resilience KPIs: Penalty of change, Recovery Time, Knowledge transfer time
- I5.0 human centricity KPIs: Absenteeism (3ple P), # of human positions, Workload reduction, Wellness indicators
- I5.0 social KPIs: Real free time
- I5.0 sustainability skills: Forward thinking (*HBS, n.d.*), empathy
- I5.0 resilience skills: problem solving (soft); AR/VR (hard); digitalisation (hard/soft); critic, deductive, inductive thinking.
- I5.0 human centricity skills: use of AI in collaborative decision making (hard); Inclusiveness.
- I5.0 social skills: communicative speaker; Active listening; language learning; management skills
- I5.0 sustainability technologies: IoT, AI, Blockchain,3D printing (2021 World Manufacturing Report: Digitally Enabled Circular Manufacturing)
- I5.0 resilience technologies: IoT, AI, Blockchain,3D printing, parametric design.
- I5.0 human centricity technologies: human-centred AI (i.e. explainability), Collaborative robots
- I5.0 social technologies: language instant translators
- I5.0 sustainability strategies: 3ple bottom line aspects; Zero-defect; circular economy; eco-design
- I5.0 resilience strategies; Flexibility increase; Frugality
- I5.0 human centricity strategies: 3ple bottom line aspects; Human inclusion / empowerment; Ergonomics department; Inclusiveness
- I5.0 social strategies: CSR; SDG 3,4,5
- I5.0 sustainability organisational aspects: Working conditions, sustainability of the job.
- I5.0 resilience organisational aspects: change management scheme; resilience of job
- I5.0 human centricity organisational aspects: co-creation / co-design procedure; mentality change
- I5.0 social organisational aspects: industrial symbiosis

Additionally, a taxonomy of technologies that can be helpful (beyond the Key Enabling Technologies of Industry 5.0) can be found in the literature (Stavropoulos et al., 2023).

Annexe 3 – Design Template for TLF5.0 (the case of companies).

Preparation period

Preparation of learning material & delivery mechanism, Description of learning material and phases, Purchase of new equipment, Set-up of (new) technologies, Trainer's selection. A schedule needs to be included.

Decide on the TF/LF combination.

Type	*	From		To	
Type	*	From		To	
..					

* TF/LF/AppF/Courses

Decide on the details.

Overall characteristics

Define exact learning outcomes[7] /attitude/mentality change, make sure there are links to the WP objectives (O1-O6)

(For courses) What is the desired content?

(For TF) What is the problem that the participants must face? If described in D5.1, ignore.

Definition of the problem

Definition of requirements and Integration of the three Pillars

Definition of the sessions and the timeline

Type	*	**	From		To	
Type			From		To	

*Problem presentation/Problem solution/..

[7] It would be preferable that they are stated in S.M.A.R.T. form, possibly utilising Bloom's taxonomy (UTICA, n.d.)

** Online Synchronous/Online asynchronous/..

(For LF) What is the product that the participants must produce? If described in D6.1, ignore.

Definition of the manufacturing processes involved.

Definition of extra requirements and Integration of the three Pillars

Definition of extra aspects (i.e. communications, cooperation, co-creation, commercialisation plans)

Participants

Knowledge background

Required job skills.

Set different target groups and assign roles.

Define Stakeholders, i.e. unions; more can be found in literature (Stavropoulos et al, 2021).

Extra procedures

For public documents, ensure that you include only non-sensitive data.

GDPR forms

Documentation of the procedure

- Medium (i.e. recordings and DOCX)
- the details (i.e. criteria of the final choice)
- FTL

Evaluation aspects

New knowledge from courses: Did the participants of the TF understand and learn the lessons and methods? Could the participants apply their new knowledge in their home company?

Time localisation of evaluation timing (before and after for both company and trainees)

Evaluation of the participants and the intervention

- Different template (Annexe 4)
- Quantifiable KPIs for the above

Annexe 4 – Evaluation Template for TLF5.0 (the case of companies).

This evaluation template has been assembled primarily through brainstorming between the partners. Questions from the Workplace Innovation questionnaires have also been integrated. The main idea is to keep it minimal, covering various aspects, including upskilling, strategies, practices, directions (from D1.1), adoption, quantification of impact, and, above all, a feasibility check.

In the future, this can be generalised by integrating more questions. It is briefly noted herein that, for the case of sustainability, specialised questionnaires from B Corporation offer possibilities towards sustainability certification (BCORP, n.d.), as well as similar procedures outlined in ISO 14001:2015. For human centricity, there are extended questionnaires from Workplace Innovation, while for resilience, APMG has a programme (APMG, n.d.), and Centric Consulting has a business-focused assessment questionnaire too (CentricConsulting, n.d.).

Part A: Intervention evaluation

Upskilling (purely indicatively)

This is run both before and after the intervention.

Question	Evaluation	Justification
Do you feel confident in solving problems during the manufacturing process?	5. Extremely high 4. Moderately high 3. Neutral, neither high nor low 2. Moderately low 1. Extremely low	Justification – please explain what should be at level 5
Do you feel confident in using shared control between human and machine?	5. Extremely high 4. Moderately high 3. Neutral, neither high nor low 2. Moderately low 1. Extremely low	
Do you feel confident in working in different project at the same time?	5. Extremely high 4. Moderately high 3. Neutral, neither high nor low 2. Moderately low 1. Extremely low	

Do you feel confident in working in different working areas in the company?	5. Extremely high 4. Moderately high 3. Neutral, neither high nor low 2. Moderately low 1. Extremely low	

Usefulness, Ease & Impact of intervention

This is run after the intervention.

Question	Evaluation	Justification
How easy was it to implement the intervention?	5. Extremely easy 4. Moderately easy 3. Neutral 2. Moderately hard 1. Extremely hard	
Is the intervention generic enough to be of interest to distinct groups of trainees?	5. Extremely generic 4. Moderately general 3. Neutral general 2. Moderately general 1. Extremely low general	
How easy is it to extend the intervention within the company, to other departments?	5. Extremely easy 4. Moderately easy 3. Neutral 2. Moderately hard 1. Extremely hard	
How are groups of operators and managers involved in the design/ implementing of the intervention? Are they given time and resources required to enable their active involvement? If they were not involved, please explain why.		
What aspects would you add to such interventions, so that you achieve targets, such as management structure change?		

Implications for organisational changes

This is run either before or after the intervention.

Question	Justification
Is senior management really committed to the intervention? How do you know?	
What are the intended outcomes in terms of company performance?	
How will the delegation of decision-making affect the existing management structure and management roles?	
How will the intervention contribute to achieving your company's strategic goals?	

Implications for mentality changes

This is run after the intervention.

Question	Justification
Does the company give opportunities to improve your skills?	
How would you assess the culture of the company and its impact on the willingness and ability of frontline workers to participate in the intervention? Do you need to make any changes to the company culture – and if so, how will you do it?	
Will you need to support managers in making the transition from their current roles? If so, how?	

Engagement of company in terms of practices

This is run both either before, and after the intervention.

Question	Justification
Have you anticipated potential sources of resistance? What is the best way of dealing with it?	
How will you avoid 'innovation decay' (i.e.: drifting back to the old ways)? How are you sure interventions will last?	
What else would really make this intervention successful?	

Part B: Company side (per pillar)

Part B is run both before and after the intervention.

Human Centricity

Question	Evaluation	Justification
Will there be/are there changes in mentality of the work among the trainees-employees? *(HC1)*	5. Extremely high expectations 4. Moderately high expectations 3. Neutral, neither high nor low expectations 2. Moderately low expectations 1. Extremely low expectations	
Will reduction of physically arduous tasks be achieved? *(HC2)*	5. Yes 3. Partially 1. No	
How effectively does this company support and implement worker participation in decision-making processes related to both change initiatives and daily operations? *(HC3)*	5. Extremely high effective 4. Moderately high effective 3. Neutral, neither effective nor ineffective 2. Moderately low effective 1. Extremely low effective	
How effectively does this company support the implement worker empower its participants through, inclusive decision-making, and fostering inclusivity? *(HC4)*	5. Extremely high 4. Moderately high 3. Neutral, neither high nor low 2. Moderately low 1. Extremely low	
How effectively does this company support and implement opportunities for day-to-day learning? *(HC5)*	5. Extremely high opportunities 4. Moderately high opportunities 3. Neutral, neither high nor low opportunities 2. Moderately low opportunities 1. Extremely low opportunities	
How effectively does this company support and implement opportunities to reduce monotony? *(HC6)*	5. Extremely high opportunities 4. Moderately high opportunities 3. Neutral, neither high nor low opportunities 2. Moderately low opportunities 1. Extremely low opportunities	

How effectively does this company support and implement enhanced work autonomy for frontline workers? *(HC7)*	5. Extremely high work autonomy 4. Moderately high work autonomy 3. Neutral, neither high nor low work autonomy 2. Moderately low work autonomy 1. Extremely low work autonomy	
How effectively does this company support and implement employee-driven improvement and innovation? *(HC8)*	5. Extremely high 4. Moderately high 3. Neutral, neither high nor low 2. Moderately low 1. Extremely low	
(FROM D1.1 DIRECTIONS) **Does the company support and implement shared control between humans and machines? *(HC9)***	5. Yes 3. Partially 1. No	
(FROM D1.1 DIRECTIONS) **To what extent does the company promote delegation of decision-making from managers to workers? *(HC10)***	5. Extremely high 4. Moderately high 3. Neutral, neither high nor low 2. Moderately low 1. Extremely low	

Sustainability

Question	Evaluation	Justification
To what extent does the company promote and engage in reductions in energy consumption? *(S1)*	5. Extremely high 4. Moderately high 3. Neutral, neither high nor low 2. Moderately low 1. Extremely low	
To what extent does the company promote and engage in reduced CO2 output? *(S2)*	5. Extremely high 4. Moderately high 3. Neutral, neither high nor low 2. Moderately low 1. Extremely low	
To what extent does the company promote and engage in waste reduction? *(S3)*	5. Extremely high 4. Moderately high 3. Neutral, neither high nor low 2. Moderately low	

	1. Extremely low	
To what extent does the company promote and engage in greater reuse and recycling of materials? *(S4)*	5. Extremely high 4. Moderately high 3. Neutral, neither high nor low 2. Moderately low 1. Extremely low	
To what extent does the company promote and engage in life cycle analysis? *(S5)*	5. Extremely high 4. Moderately high 3. Neutral, neither high nor low 2. Moderately low 1. Extremely low	
To what extent does this company work towards reducing primary energy consumption? *(S6)*	5. Extremely high 4. Moderately high 3. Neutral, neither high nor low 2. Moderately low 1. Extremely low	
(FROM D1.1 DIRECTIONS) **To what extent does the company promote and engage in caring about the environment? *(S7)***	5. Extremely high 4. Moderately high 3. Neutral, neither high nor low 2. Moderately low 1. Extremely low	
(FROM D1.1 DIRECTIONS) **To what extent does the company promote and engage in making and promoting green choices? *(S8)***	5. Extremely high 4. Moderately high 3. Neutral, neither high nor low 2. Moderately low 1. Extremely low	

Resilience

Question	Evaluation	Justification
Are procedures robust within the company? *(R1)*	5. Yes 3. Partially 1. No	
Is time of recovery used as KPI in company procedures? *(R2)*	5. Yes 3. Partially 1. No	
To what extent does the company promote self-organised teamwork? *(R3)*	5. Extremely high 4. Moderately high 3. Neutral, neither high nor low 2. Moderately low	

	1. Extremely low	
To what extent does the company promote the flatter organisational structure? *(R4)*	5. Extremely high 4. Moderately high 3. Neutral, neither high nor low 2. Moderately low 1. Extremely low	
(FROM D1.1 DIRECTIONS) **Does the company encourage creativity and flexibility in manufacturing processes? *(R5)***	5. Yes 3. Partially 1. No	
(FROM D1.1 DIRECTIONS) **Does the company encourage innovation? *(R6)***	5. Yes 3. Partially 1. No	
(FROM D1.1 DIRECTIONS) **To what extent does the company promote and engage in resilient supply chains? *(R7)***	5. Extremely high 4. Moderately high 3. Neutral, neither high nor low 2. Moderately low 1. Extremely low	
(FROM D1.1 DIRECTIONS) **To what extent does the company promote and engage in the implementation training and education systems that guarantee the availability of knowledge and skills? *(R8)***	5. Extremely high 4. Moderately high 3. Neutral, neither high nor low 2. Moderately low 1. Extremely low	

Annexe 5 – AI as educational medium.

To investigate the capability of AI in effectively conveying technical subject matter to trainees, a controlled experiment was designed. Participants were randomly assigned to two groups: a control group, in which traditional training was conducted, and an experimental (test) group, in which instruction on finite differences was delivered exclusively through an AI-based system. The selection of a process-level technical topic ensured that the focus remained on skill acquisition without introducing broader systemic variables linked to Industry 5.0 pillars. The experimental design enabled the careful control of key factors, including prior knowledge, training duration, and performance evaluation, ensuring that differences in learning outcomes could be attributed primarily to the quality of the AI instruction. All the trainees signed informed consents.

Finite differences, in particular, were selected as the subject of training due to their technical nature, which allows for more objective measurement of performance outcomes. This has been an established method for building numerical models for manufacturing processes (Foteinopoulos et al, 2024). The structured and procedural characteristics of finite difference methods enable precise tracking of learner progress and clear evaluation of task accuracy. Moreover, the training timeframe can be tightly controlled. Because finite differences require specific procedural knowledge rather than subjective interpretation, participants' opinions are more likely to reflect their actual skill acquisition with minimal bias. Additionally, prior knowledge can be effectively managed, as introductory material is easily standardised, ensuring a uniform baseline across all participants. These characteristics make finite differences an ideal subject for studying training effectiveness within a controlled experimental framework.

The assumptions for the design of the educational pilots that have been made are:

- It was decided initially that all participants who know how to use finite differences will be excluded.
- In the trial group, Generative AI will retrieve all information.
- The outline of the class was given to the trial group.
- Generative AI must not be used to create code.
- The problem statement was given in written form to the trial group.
- Example code for specific algorithm of “double for” structure was given to both groups.

The overall procedure involved many steps, which are briefly given in Table 43.

The class outline itself included many fundamental aspects of the computational universe and is presented in Table 44.

Topic	Elaboration
Tailor expansion	The link between a function and its derivatives
Finite Differences	What they are
Their link	How are the previous two concepts linked
Laplace Equation & Poisson equation	What they are and how they are usually solved
1D of Laplace Equation	How the Laplace Equation is reduced to one dimension
Octave commands (for, inv, plot, if)	Samples of syntax
Finite Differences (FD) in a discretised space with five points (Laplace equation - 1D)	What the derived equations are
Forming the equations of FD in matrix notation	How the resulting algebraic system is transcribed into matrices $\tilde{A}\vec{x}=\vec{b}$
Double for	How a sparse system can be filled in with a “double for” structure
The Convergence concept	What convergence is and why we need it

Table 43: The structure (outline) of the course.

Also, the evaluation procedure has been designed. As seen in Table 44, the questions control the background (Qb), timekeeping (Tn), and questions for after the course (Qa). Finally, there has been a question for the trainees to write their opinions /feelings (Qc).

Code	Question	Response
Qb1	Do you have any programming background?	Nothing at all, I have heard of it, I have studied it, but I do not remember it, I think I can manage it, I collaborate with it
Qb2	What is your current status?	Student, Graduate Student, Graduate
Qb3	Do you have any background in computational methods / numerical analysis, or related fields?	Nothing at all, I have heard of it, I have studied it, but I do not remember it, I think I can manage it, I collaborate with it
Qb4	What do you know about finite differences in particular?	Nothing at all, I have heard of it, I have studied it, but I do not remember it, I think I can manage it, I collaborate with it
Tn	Time keeping	Beginning, end of reading, end of practice, end of evaluation
Qa1	I feel confident in explaining the concept of Finite Differences to a third person	1 (strongly disagree) – 5 (strongly agree)
Qa2	I feel confident in explaining the concept of convergence to a third person	1 (strongly disagree) – 5 (strongly agree)
Qa3	I feel confident in modifying the code from solving a Laplace equation to solving a Poisson equation	1 (strongly disagree) – 5 (strongly agree)
Qa4	I feel intrigued in learning more about the method	1 (strongly disagree) – 5 (strongly agree)
Qc	Comments you may have on the procedure	Free text

The results have been very interesting; their statistical elaboration is presented hereafter. To begin with, responses to control questions are shown in Table 44. The observed differences across groups likely occurred by chance, as indicated by the test results. Regarding timekeeping, Table 45 indicates several differences between the two groups. In particular, differences in practice times are statistically significant; in fact, they are much smaller in the case of the control group.

Variable	Normal	Common variance	Test	Confidence Interval Low Limit [min]	Confidence Interval High Limit [min]
Total time	No	-	Mann-Whitney U	-51	-10
Studying	No	-	Mann-Whitney U	-15	5
Practice	Yes	No	Welsch's t	-49	-15

Table 44: Independent t-tests for timing variables. Negative values mean Control Group had better performance.

Regarding their confidence, it appears that the results are not conclusive in a statistical sense, as the confidence intervals' limits do not have the same sign. However, in the case of Qa2, it is marginally generalizable since the lower limit is very close to zero. Fig. 2 also displays the confidence intervals for the two groups separately, as shown in the case of Qa2 (The jamovi project, 2022; R Core Team, 2025).

Variable	Normal	Common variance	Test	Confidence Interval Low Limit	Confidence Interval High Limit
(Qa1+Qa2+ Qa3+Qa4)/4	Yes	Yes	Student's t	0.05	1.59

Table 45: Independent t-tests for results. Positive values mean Control Group had better performance.

To complement the quantitative findings, a set of qualitative responses was collected from participants following the AI-led training session on finite differences (Qc). These responses provide insight into the perceived clarity, support, and limitations of using AI tools in understanding both the theoretical and practical aspects of the subject. Overall, participants found the theoretical content generally understandable, with AI offering helpful guidance, especially in basic concepts and coding support. However, several responses highlighted the limitations of AI in entirely replacing expert instruction, particularly for complex or unfamiliar material.

There are also comments from the instructor himself, who was present in both sessions.

- The case of five variables has been quite challenging for students to elaborate.
- specifically, forming the 5x5 matrix
- Additionally, handling if conditions was not straightforward.
- During the “inv” command applicability, there were also some challenges.
- Generally speaking, the case of five variables has been quite hard, and the intervention of the instructor was necessary for the coding to be concluded.
- One inconclusive report occurred, as retrieving the 5x5 matrix was not possible, and major delays occurred. The timing was considered the maximum time for the rest of the participants.

It is noted that there is a very small difference between the two groups in the cases of Qa3 and Qa4. This is also reflected in the respective confidence intervals. Additionally, given the directness of these questions, they can be used as bias estimators. Taking (UPPER-

LOWER)/LOWER as a metric, this results in approximately 8% for Qa3 and Qa4. In the case of total time and Qa1, the percentages are 76% and 41%, so they are quite trustworthy.

Annexe 6 – Relevant scientific publications.

Aspect	First published in
Template	Papacharalampopoulos, A., Stavropoulos, P., Ziarsolo, U., & Karagianni, O. M. (2024, July). Teaching Learning Factories 5.0: Shaping Training, Skilling, and Reskilling for the Future. In International Association for the Management of Technology Conference (pp. 159-167). Cham: Springer Nature Switzerland.
Evaluation	Papacharalampopoulos, A., Karagianni, O. M., Stavropoulos, P., Ziarsolo, U., Totterdill, P., Exton, R., ... & Elorza, U. (2025). On a heuristic evaluation system for Industry 5.0 with respect to interventions: the case of training in businesses. Procedia CIRP, 132, 122-128.
Behavioural TF as well as soft/partial intervention) (Mondragon and TK)	BRIDGES 5.0 Conference in Leuven
Comau case	CIRP ICME 2025
Kitron case	GCSM 2025
AI as educational medium	ESAIM 2025

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BRIDGES 5.0 PROJECT IDENTITY

Project name	BRIDGES 5.0 **B**ridging **R**isks to an **I**nclusive **D**igital and **G**reen future by **E**nhancing workforce **S**kills for industry 5.0
Coordinator	**Prof. Dr Steven Dhondt (scientific coordinator)** **Nederlandse Organisatie Voor Toegepast Natuurwetenschappelijk Onderzoek (TNO, Netherlands)**
Consortium	Katholieke Universiteit Leuven Austrian Institute of Technology Panepistimio Patron (Patras University) Conservatoire National des Arts et Métiers, Centre d'Études de l'Emploi et du Travail-Lirsa Departamento de Educacion del Gobierno Vasco The University of Warwick Technische Universität Dortmund Stichting Platform Beta en Techniek Mondragon Goi Eskola Politeknikoa, Jose Maria Arizmendiarrieta S Coop Lietuvos Pramonininku Konfederacija Universita degli Studi di Bari Aldo Moro Universitetet I Agder Workplace Innovation Europe CLG Comau SPA Infineon Technologies Austria AG UAB Kitron Industrie 4.0 Plattform Osterreich Kriziu tyrimo centras (Hybridlab) FH Joanneum Gesellshaft MBH Kauno Technologijos Universitetas
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Duration	2023-2027

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