LCAMP Observatory:

Learning Factories for Advanced Manufacturing Skills in Vocational Education

WP3 Observatory

LCAMP partners:

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Author/s	Rikardo Lamadrid Intxaurraga
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GLOSSARY AND/OR ACRONYMS

AGV - Automated Guided Vehicles
AR - Augmented Reality
CLF - Collaborative Learning Factory
CoVE - Centres of Vocational Excellence
DFMA - Design Failure Mode & Effect Analysis
EXAM4.0 - Excellence Advanced Manufacturing 4.0
EQF - European Qualifications Framework
ERP - Enterprise resource planning
HVET - Higher Vocational Education and Training

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EXECUTIVE SUMMARY

This report presents an in-depth analysis -combining literature review and interviews conducted with experts and practitioners- of the use and implementation of Learning Factory-like settings in 30 VET and HVET institutions between EQF levels 3 and 6 based in 8 European countries and the advantages and disadvantages they pose on the development of skills regarded as useful by Advanced Manufacturing companies according to our previous observatory reports.

This report analyses the role, implementation, and potential of Learning Factories (LFs) in Vocational Education and Training (VET) in Europe. It is based on a combination of desk research and field research, integrating evidence from project reports, academic literature, and interviews with VET schools and European project experts. The objective is to assess whether and how Learning Factories can contribute to addressing current and future skills needs, particularly in the context of digital and green transitions.

The desk research draws on key outputs of the LCAMP project and other European initiatives, including analyses of advanced manufacturing jobs, skills frameworks, policy recommendations, and international research on Learning Factories. This analysis shows that advanced manufacturing is characterised by rapid but uneven technological adoption, strong pressures from digitalisation and sustainability, and highly context-dependent job evolution. Companies increasingly demand a **versatile workforce** with strong foundational, digital, and transversal skills, complemented by process-specific specialisation developed through experience. At the same time, few entirely new job profiles are emerging; instead, existing roles are being reshaped by additional functions linked to digital and green transformations.

Within this context, Learning Factories are identified as a highly promising educational approach. They enable learning in close-to-real production environments, where technologies are embedded within complete value chains rather than taught as isolated tools. This allows learners to develop a holistic understanding of production processes, work organisation, and the role of technology in achieving business objectives. Learning Factories also support active, experiential learning methodologies and align strongly with the LCAMP skills framework, particularly in combining foundational knowledge, transversal competences, and contextualised specialisation.

The field research complements these findings through interviews with VET schools implementing Learning Factories and with experts from European projects such as BRIDGES 5.0, SkillAIbility, EXAM4.0, VLF4EU, and LF4VET. The interviews confirm that Learning Factories are increasingly used as strategic tools to modernise VET provision, integrate new technologies, and enhance learner engagement. In VET schools, Learning Factories typically build on existing workshops, extend active learning methodologies, and are shared across multiple study programmes to foster interdisciplinary collaboration. However, they are still at an early stage of institutionalisation, and external stakeholders, particularly companies, are not always aware of Learning Factories as a distinct pedagogical model.
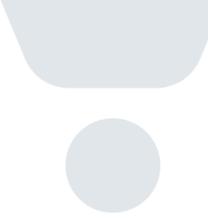
The interviews with European project experts further confirm the relevance of Learning Factories for both initial VET and continuing VET (CVET), highlighting their potential for worker upskilling and reskilling. They also bring additional insights not fully captured in the desk research, notably the value of Learning Factories for inclusion, especially for learners with disabilities, and the growing importance of virtual and hybrid Learning Factories to improve accessibility, scalability, and cost-effectiveness. At the same time, both schools and projects report a lack of robust, standardised impact measurements, with most evidence still being qualitative and exploratory.

Several limitations must therefore be acknowledged. The sample of interviewed institutions and projects is relatively small and geographically concentrated, and the Learning Factory approach is still too recent in many contexts to allow for definitive conclusions about long-term impact. More systematic research, larger samples, longitudinal studies, and shared evaluation frameworks are needed.

Despite these limitations, the findings of this report consistently point to the high potential of Learning Factories as a future-oriented approach for VET. While often associated with advanced manufacturing, their underlying principles, learning by doing, integration of technology into real processes, holistic understanding of value chains, and development of transversal skills, are highly transferable to other VET sectors. Promising areas include the food industry and food processing, logistics, energy and sustainability-related fields, healthcare technologies, and other process-oriented sectors.

In conclusion, Learning Factories represent a strategic opportunity for the modernisation of VET in Europe. They offer a concrete pathway to align education with evolving labour market needs, support digital and green transitions, foster inclusion and lifelong learning, and strengthen collaboration between VET providers and industry. Further research and policy support will be key to unlocking their full potential.

1. INTRODUCTION

This report presents the results of a mixed-methods research activity focused on the role and potential of Learning Factories (LFs) in the field of vocational education and training (VET) related to advanced manufacturing in Europe. The work combines desk research and field research to provide an evidence-informed, practice-oriented analysis that can be useful for VET providers, policymakers, researchers, project designers, and other stakeholders across different European contexts.

The desk research involved the analysis of existing reports, policy documents, project outputs, and academic and grey literature related to Learning Factories, work-based learning, competence-based education, and technological innovation in VET. This phase aimed to identify prevailing definitions, implementation models, pedagogical approaches, and reported benefits and challenges associated with Learning Factories.

The field research consisted of semi-structured interviews with:

- Experts from European projects; and
- VET schools and training centres that are currently implementing Learning Factory approaches in their educational offer.

These interviews provided qualitative insights into real-world implementation, perceived impacts, organisational requirements, and pedagogical value, complementing the findings from the desk research with practitioner and expert perspectives.

Based on the triangulation of desk and field research results, the report infers conclusions that are transferable and usable across Europe, while acknowledging differences in national VET systems, institutional capacities, and sectoral contexts. The intention is not to propose a single Learning Factory model, but rather to identify common patterns, enabling conditions, and recurring challenges that can inform future initiatives.

At the same time, the study recognises several limitations. The number of analysed cases and interviewed stakeholders is relatively limited, and robust impact measurements (e.g. longitudinal data, learning outcome benchmarks, cost–benefit analyses) are often missing or not yet available. As a result, many findings reflect subjective assessments, professional judgement, and individual experiences rather than fully objective or standardised indicators of effectiveness. This limitation is common in emerging educational innovations and should be taken into account when interpreting the results.

Consequently, the report highlights the need for further and more systematic research in the future. This includes larger samples, comparative studies across countries and sectors, and the development of shared frameworks and indicators to better assess the educational, organisational, and socio-economic impact of Learning Factories in VET.

Despite these limitations, the research clearly indicates that Learning Factories represent a promising and forward-looking approach for the future of VET. While they are often associated with advanced manufacturing and high-tech industrial environments, the findings suggest significant untapped potential in less technologically advanced sectors, such as food production, food analysis, and processing, where Learning Factory principles can support experiential learning, quality assurance, sustainability, and skills relevance.

This report is structured as follows:

- Results of the desk research, presenting key findings from existing literature and project documentation;

- Results of the interviews with experts from other projects, focusing on cross-project insights and strategic perspectives;
- Results of the interviews with VET schools, highlighting implementation practices and institutional experiences;
- Analysis and synthesis of the research results, addressing the main advantages and disadvantages of Learning Factories in VET;
- Conclusions, summarising key messages and recommendations; and
- Annexes, providing additional methodological details, interview guides, and supporting materials.

2. METHODOLOGY

This study adopted a qualitative, exploratory research design, combining desk research and field research methods. The methodological approach was chosen to capture both consolidated knowledge from existing studies and projects, and practice-based insights from experts and VET institutions directly involved in the design and implementation of Learning Factories. The methodology is structured into two complementary components: (1) analysis of reports and bibliographic sources, and (2) interviews with experts and practitioners.

2.1. ANALYSIS OF REPORTS AND BIBLIOGRAPHIC SOURCES (DESK RESEARCH)

The desk research aimed to establish a solid conceptual and empirical foundation for understanding the role of Learning Factories in VET, their pedagogical models, competence frameworks, and implementation challenges. The analysis focused on four main groups of sources.

First, an in-depth review was conducted of key deliverables and reports produced within the LCAMP project, including:

- WP6 – D6.1 "Research on the Role of Learning Factories in VET Education", which provided an initial analytical framework and evidence on Learning Factories in VET contexts;
- WP6 – D6.2 "Morphology of the LCAMP Collaborative Learning Factory", offering a structured description of the Learning Factory concept developed in the project;
- Policy recommendations developed in WP2, contributing insights into alignment with European VET and skills policies;
- D3.2 reports on the analysis of advanced manufacturing jobs, produced at months 24 and 36, covering multiple countries and providing labour market and occupational perspectives relevant to VET and Advanced Manufacturing;
- WP5 – D5.2 "Skills Assessment Toolkit", which informed the analysis of competence development, assessment approaches, and skills frameworks linked to Learning Factory-based learning.

Second, the desk research included the analysis of outputs from other European Union–funded projects addressing Learning Factories, digitalisation, and skills development, namely:

- BRIDGES 5.0, focusing on Industry 5.0 skills and human-centred production;
- SkillAIbility, addressing AI-related skills and inclusive competence development;
- EXAM4.0, with a focus on assessment methodologies for Industry 4.0 competences.

These projects provided comparative perspectives, alternative implementation models, and complementary methodological approaches.

Third, the study reviewed proceedings from the Conference on Learning Factories organised by the International Association of Learning Factories (IALF). These proceedings offered insights into state-of-the-art research, emerging trends, and international experiences in Learning Factory design, operation, and evaluation.

Finally, a selection of academic and institutional bibliographic sources was analysed to contextualise project-based findings within the broader research landscape. Key references included, among others:

- Roll, M. I. (2021). Learning Factories 4.0 in technical vocational schools: can they foster competence development?
- Pittich, D. T. (2020). Learning factories for complex competence acquisition. European Journal of Engineering Education;
- OECD (2021). Promoting innovative pedagogical approaches in vocational education and training;
- Enke, J., et al. (2018). Industrie 4.0: competencies for a modern production system – a curriculum for learning factories;
- Abele, E., et al. (2015). Learning Factories for Research, Education, and Training.

Together, these sources supported a comprehensive analysis of pedagogical rationales, competence models, and structural characteristics of Learning Factories in VET and higher education contexts.

2.2. INTERVIEWS WITH EXPERTS AND PRACTITIONERS (FIELD RESEARCH)

The desk research was complemented by qualitative field research based on semi-structured interviews. The objective was to capture experiential knowledge, implementation realities, and expert reflections that are not always documented in formal reports. Two main groups of interviewees were involved.

First, interviews were conducted with experts and practitioners from VET schools implementing Learning Factory approaches. These interviews focused on institutional motivations, pedagogical integration, infrastructure and resource requirements, teacher competences, learner engagement, and perceived benefits and challenges. The schools represented different national and institutional contexts, allowing for a diversified set of perspectives. Here the list of interviwed scholls:

1. Campus des Métiers et des Qualifications d'Excellence (CMQE) France
2. Duale Hochschule Baden-Württemberg (DHBW) Germany
3. Curt Nicolin Gymnasiet (CNG) Sweden
4. MADE - Competence Center Industria 4.0 Italy
5. Šolski center Nova Gorica Slovenia

6. GEBKİM Kimya İhtisas Mesleki ve Teknik Anadolu Lisesi Turkey
7. Camosun College Canada
8. CIFP Andra Mari LHII Basque Country
9. CIFP Zornotza LHII Basque Country
10. CIFP Barakaldo LHII Basque Country
11. CIFP Tartanga LHII Basque Country
12. CIFP Saturtzi LHII Basque Country
13. CIFP Iurreta LHII Basque Country
14. CIFP Bidebieta LHII Basque Country
15. CIFP Txurdinaga LHII Basque Country
16. CIFP Elorrieta-Erreka Mari LHII Basque Country
17. CIFP Aretxabaleta Lanbide Eskola LHII Basque Country
18. CIFP Politécnico Easo Politeknikoa LHII Basque Country
19. CIFP Tolosaldea LHII Basque Country
20. CIFP Armeria Eskola LHII Basque Country
21. CIFP Miguel Altuna LHII Basque Country
22. CIFP Usurbil LHII Basque Country
23. CIFP De Innovacion Social LHII Basque Country
24. CIFP Izarraitz LHII Basque Country
25. CIFP Bidasoa LHII Basque Country
26. CIFP Maq.-Herramienta LHII Basque Country
27. CIFP Don Bosco LHII Basque Country
28. CIFP Mendizabala LHII Basque Country
29. CIFP Laudioalde Lanbide Eskola LHII Basque Country
30. TKNIKA Basque Research and Innovation Center Basque Country

Second, interviews were carried out with representatives and experts from European projects actively working on Learning Factories and related innovations, including BRIDGES 5.0, SkillAIbility, LF4VET, VirtualLF4EU.

These interviews provided cross-project insights into strategic objectives, methodological choices, scalability issues, and future directions for Learning Factories in European VET systems.

The interviews followed a flexible guide to ensure comparability while allowing interviewees to elaborate on context-specific experiences. Data from the interviews were analysed thematically and triangulated with desk research findings to identify recurring patterns, convergences, and divergences.

Overall, the combination of desk research and field research enabled a holistic and practice-informed analysis, while also revealing methodological limitations related to sample size, subjectivity, and the current lack of standardised impact measurement tools. These aspects are further discussed in the analytical sections of the report.

3. DESK RESEARCH: SKILLS NEEDS AND THE ROLE OF LEARNING FACTORIES

3.1. SKILLS NEEDS IN ADVANCED MANUFACTURING

The analysis of the WP3 Observatory reports produced at months 24 and 36 provides a detailed picture of skills needs and job evolution in advanced manufacturing across different European contexts.

Overall, the reports confirm the widespread diffusion of new technologies in manufacturing, while also highlighting that their actual implementation in production processes is highly uneven. In many companies, the level of technological adoption remains lower than initially expected, reflecting constraints related to investment capacity, organisational readiness, workforce skills, and regulatory frameworks. This variability has direct implications for skills demand, as workers are required to operate in hybrid environments where traditional and digitalised processes coexist.

Two major and interrelated trends clearly emerge: digitalisation and greening. Digital technologies are increasingly embedded in production, maintenance, logistics, and quality control, while environmental sustainability is progressively shaping production strategies, energy management, and process optimisation. These transitions are not occurring in isolation, but rather jointly redefining occupational profiles and competence requirements.

The reports describe a dynamic job landscape, in which occupations in advanced manufacturing are undergoing continuous transformation as a result of the digital and green transitions. Rather than leading to a complete replacement of existing jobs, these transitions are mainly reshaping job content, tasks, and responsibilities.

Job evolution is strongly influenced by the industrial context. Factors such as company size, level of digital maturity, type of production, business strategy, organisational culture, and regulatory environment play a decisive role in determining how technologies are adopted and how jobs evolve. Consequently, there is significant variability in job evolution, even for similar occupational profiles, depending on the individual company.

Digital transformation initiatives are primarily driven by the objective of enhancing company performance, for example, improving efficiency, quality, traceability, or flexibility. Less emphasis is placed on individual well-being as an explicit driver of technological change, although indirect effects on working conditions may still occur.

The reports also note a limited identification of entirely new job roles. Apart from data analytics, related positions, which are more frequently mentioned in larger companies, most changes concern existing roles rather than the creation of new occupations.

Significant changes are observed in specific roles, particularly in maintenance, Technical Assistance Services (TAS), and automation-related functions. These roles increasingly integrate digital monitoring, data interpretation, and system optimisation tasks alongside traditional responsibilities. In many cases, job evolution takes the form of adding new functions derived from digital and green transformations to existing job profiles.

From a skills perspective, companies consistently emphasise the need for a versatile workforce. Desired characteristics include a flexible mindset towards change, motivation and ability to learn continuously, effective communication skills, and strong problem-solving abilities. These transversal competences are seen as essential to cope with rapidly evolving technologies and processes.

At the same time, companies express demand for highly specialised profiles tailored to their specific manufacturing processes. This specialisation is often developed through in-house training and work experience, building on the foundations provided by initial VET. A key message emerging from the reports is that specialisation is only effective when it is grounded in strong foundational skills; without a solid base, meaningful specialisation is not possible.

Accordingly, VET profiles are expected to combine sound fundamental knowledge, proficiency in digital skills, foreign languages, and well-developed transversal skills. This combination is considered critical to meeting the evolving demands of advanced manufacturing occupations.

Finally, the reports highlight that climate emergency measures are more actively pursued by larger companies, for example through automated carbon footprint calculations or improvements in energy efficiency. However, these practices are still at an early stage and far from being fully consolidated across the sector.

3.2. LEARNING FACTORIES AND THEIR RELATION TO SKILLS FOR ADVANCED MANUFACTURING

Within this context, Learning Factories emerge as a pedagogical and organisational response to the evolving skills needs of advanced manufacturing. A Learning Factory is commonly defined as a close-to-reality factory environment for education, training, and research purposes, which enables experiential learning in a realistic industrial setting" (Abele et al., 2017).

Learning Factories are semi-industrial learning environments specifically designed to support the integration of Industry 4.0 technologies and infrastructures into education and training. Unlike isolated laboratories or technology-focused training spaces, Learning Factories reproduce production processes in a systemic way, allowing learners to engage with technologies as they are embedded in real operational contexts.

A key characteristic of Learning Factories is their capacity to foster interdisciplinary cooperation. Multiple disciplines, such as production, automation, logistics, quality management, IT, and sustainability, can operate within the same Learning Factory. This mirrors the complexity of real industrial environments and aligns well with the multifaceted skills requirements identified in advanced manufacturing jobs.

By enabling learning through realistic production scenarios, Learning Factories directly address the need for workers who can combine technological competence, process understanding, and transversal skills, as highlighted in the WP3 Observatory reports.

3.3. CONCLUSIONS OF THE DESK RESEARCH: INFERRED INSIGHTS

Based on the analysis of reports and literature, several key inferences can be drawn regarding the role of Learning Factories in VET.

First, Learning Factories appear highly promising as a means to reduce skills mismatch in advanced manufacturing. By aligning learning environments with real production processes and technologies, they help bridge the gap between what is taught in VET and what is required in companies.

Second, Learning Factories represent a highly relevant approach for implementing new technologies in VET schools. They provide a structured and meaningful way to introduce digital and green technologies, even when their adoption in industry is heterogeneous.

Third, Learning Factories offer an effective mechanism to keep teachers' knowledge and skills up to date. By working in environments that reflect current industrial practices, teachers can continuously refresh their technical and pedagogical competences.

Fourth, the Learning Factory concept shows a strong alignment with the LCAMP skills framework, particularly in its emphasis on foundational skills, transversal competences, and context-specific specialisation.

A distinctive feature of Learning Factories is that digital technologies are introduced as part of an integrated production process, not as an end in themselves. The Learning Factory reproduces the entire value chain, enabling learners to understand how digitalisation supports production objectives. This holistic perspective is essential to ensure that VET students grasp digitalisation as applied to production, rather than as a collection of isolated tools.

Furthermore, Learning Factories require learners to engage in numerous non-technological decisions related to organising work, dividing tasks, coordinating roles, making decisions, and solving problems. As a result, students develop an understanding of technology that is close to real-world industrial practice, rather than learning to use devices or software in artificial or decontextualised training situations. The replication of organisational aspects also allows learners to explore different perspectives on how technology influences production and work organisation.

Companies introduce technologies for diverse and long-standing reasons—such as competitiveness, efficiency, safety, energy savings, error reduction, or automation of manual tasks. The way these technologies are implemented significantly reshapes jobs and skills. If VET providers are to remain relevant partners for industry, they must also adopt and work with these technologies. Learning Factories provide a concrete and scalable pathway to achieve this.

Within Learning Factories, students learn by doing. Those who successfully complete Learning Factory–based courses are likely to have acquired the basic skills required by companies, while also having opportunities to develop specialised competences. Moreover, the active learning methodologies typically used in Learning Factories support the development of transversal skills such as teamwork, communication, adaptability, and problem-solving. When appropriate skills frameworks are in place, Learning Factories are also well suited to assessing these transversal competences.

The subsequent sections of this report examine whether and how these inferred conclusions are confirmed by the field research, based on interviews with experts and VET schools implementing Learning Factories.

4. FIELD RESEARCH: INTERVIEWS WITH EXPERTS AND PRACTITIONERS

This section presents the structure and analytical framework of the field research based on interviews. At this stage, it provides the general outline of the section, while detailed empirical content will be incorporated once all interviews have been completed and analysed.

4.1. LEARNING FACTORIES IN VET SCHOOLS

This subsection presents the results of interviews with VET schools implementing Learning Factories, with the aim of understanding how the concept is interpreted and operationalised in real educational contexts. The analysis focuses on institutional profiles, pedagogical approaches, infrastructure and resources, technologies, teacher competences, learner engagement, perceived benefits, challenges, and sustainability considerations.

The field research involved interviews with a total of 30 VET and HVET schools across 8 countries. A significant proportion of the interviewed institutions (22 schools) are located in the Basque Country, a region with a strong tradition in industrial VET, close cooperation with companies, and early adoption of innovative pedagogical and technological approaches. While this geographical concentration influences the findings, it also provides a rich and mature set of experiences related to Learning Factory implementation.

4.1.1. INSTITUTIONAL CONTEXT AND TRAINING OFFER

The interviewed schools typically offer a broad range of VET programmes, mainly at upper-secondary and post-secondary levels, closely linked to industrial sectors such as manufacturing, automation, mechatronics, electronics, maintenance, and related fields. In several cases, Learning Factories are not isolated initiatives but are embedded within wider institutional strategies focused on innovation, digitalisation, and strong collaboration with industry.

4.1.2. UNDERSTANDING AND TERMINOLOGY OF LEARNING FACTORIES

When asked how they define a Learning Factory, most schools refer to a realistic or semi-realistic production environment designed for learning purposes, where students can work with real processes, technologies, and organisational constraints. However, the terminology used varies. Some schools explicitly use the term Learning Factory, while others refer to training plants, didactic factories, pilot lines, or advanced workshops. Despite these differences in

naming, the underlying concept is largely consistent: learning takes place through participation in integrated production processes.

4.1.3. WORKSHOPS, FACILITIES, AND INFRASTRUCTURE

All interviewed schools have a strong tradition of workshop-based training. Learning Factories are typically built on existing workshops, which are progressively upgraded with new technologies, interconnected systems, and more complex production flows. Schools emphasise that Learning Factories do not replace traditional workshops but rather evolve from them, increasing their level of integration, realism, and pedagogical ambition.

In recent years, mirroring developments in industry, workshops in VET schools have been adapting to digital transformation. Although strategies for integrating enabling digital technologies vary depending on the context, it can be said that, in one way or another, all of the schools studied are incorporating digital technologies into their workshops.

4.1.4. PEDAGOGICAL APPROACHES AND METHODOLOGIES

Before introducing Learning Factories, many schools were already experimenting with active learning methodologies, such as Problem-Based Learning (PBL), Project-Based Learning, experiential learning, or challenge-based approaches. Learning Factories are therefore often seen as a natural extension and consolidation of these methodologies, providing a physical and organisational framework where active learning can be implemented more systematically and realistically.

Among the pedagogical contributions of learning factories, three stand out: (1) students gain a holistic view of the entire value chain of production processes; (2) they make it possible to replicate organizational models found in companies within learning factories; and (3) they enable and promote collaboration across different fields of knowledge.

4.1.5. STUDY PROGRAMMES INVOLVED

Learning Factories are typically used by multiple study programmes within the same institution. These often include automation, mechatronics, industrial electronics, manufacturing, maintenance, logistics, administration and finances and IT-related programmes. In several schools, Learning Factories are explicitly designed to be shared spaces, fostering interdisciplinary collaboration among learners from different specialisations.

4.1.6. TECHNOLOGIES AND DIGITALISATION

The interviewed Learning Factories integrate a wide range of technologies, reflecting Industry 4.0 paradigms. These commonly include automation systems, robotics, sensors, PLCs, data collection and monitoring systems, and, in some cases, AI-related applications. The level of technological sophistication varies across schools, depending on resources, partnerships, and strategic priorities.

Some schools report the use of digital twins as well, although their scope and maturity differ. Digital twins are most commonly applied to specific machines, production lines, or processes rather than to entire factories. In many cases, digital twins are still under development or used primarily for simulation, monitoring, or training purposes.

4.1.7. MANUFACTURING PROCESSES COVERED

Learning Factories usually include multiple manufacturing processes, such as assembly, machining, quality control, logistics, and maintenance. The emphasis is often on demonstrating how different processes are interconnected within a production system, rather than on mastering a single isolated process.

4.1.8. MOTIVATIONS FOR INVESTING IN LEARNING FACTORIES

Schools identify several reasons for investing in Learning Factories. These include the need to better align training with industry requirements, increase student motivation and employability, modernise infrastructure, support teacher upskilling, and strengthen collaboration with companies. In many cases, Learning Factories are also seen as a way to enhance the attractiveness and reputation of the institution.

4.1.9. EXTERNAL FEEDBACK AND STAKEHOLDER PERSPECTIVES

At the time of the interviews, systematic external feedback from companies and other stakeholders is still limited. In many cases, external stakeholders are not yet fully aware of the Learning Factory concept as such, even when they collaborate with schools or benefit from graduates trained in these environments. As a result, feedback is often indirect and refers more generally to the quality of graduates or to specific training activities, rather than explicitly to Learning Factories.

Where interaction with companies exists, it is mainly focused on specific technologies, workshops, or training programmes, rather than on the Learning Factory as an integrated pedagogical model. This suggests that, in several contexts, Learning Factories are still perceived primarily as advanced workshops or upgraded training facilities, rather than as a distinct educational approach.

Overall, this indicates that Learning Factories in VET schools are still at a relatively early stage of institutionalisation and external recognition. Increasing awareness among companies and other stakeholders, as well as developing clearer communication and evaluation mechanisms, appears to be an important next step to strengthen the link between Learning Factories and the labour market.

4.1.10. CONCLUSIONS FROM THE INTERVIEWS WITH VET SCHOOLS:

The field research across 30 VET and HVET institutions reveals that Learning Factories (LFs) represent a significant evolutionary step in industrial education, moving beyond traditional workshop-based training toward integrated, digitally-driven ecosystems. Based on the findings, the following conclusions can be drawn:

- Evolutionary rather than Revolutionary Integration: Learning Factories in VET schools are not viewed as replacements for traditional workshops but as an evolution of them. They build upon a strong existing foundation of manual and technical training, adding layers of interconnectivity, realism, and complexity that mirror the digital transformation of modern industry.

- A Catalyst for Active Pedagogies: The LF model serves as a powerful physical framework for consolidating active learning methodologies like PBL and Challenge-Based Learning. By providing a holistic view of the value chain, LFs shift the focus from mastering isolated tasks to understanding integrated production processes and organizational models.

- Interdisciplinary and Collaborative Learning: One of the most significant values of the LF approach is its ability to break down "silos" between study programmes. By creating shared spaces where students from automation, logistics, IT, and administration must collaborate, LFs effectively replicate the cross-functional reality of the modern workplace.

- Bridging the Industry 4.0 Gap: While technological maturity varies, particularly in advanced areas like Digital Twins and AI, VET schools are successfully using LFs to align their infrastructure with Industry 4.0 paradigms. This investment is driven by a strategic need to maintain institutional relevance and ensure student employability in a rapidly changing labor market.

- The Need for External Institutionalization: Despite internal successes, there is a clear gap in external recognition. Many industrial stakeholders still perceive LFs as "upgraded workshops" rather than distinct pedagogical models. For LFs to reach their full potential, schools must move toward more systematic external communication and create formal feedback loops with industry partners to validate the impact of this integrated educational approach.

- Regional Maturity as a Benchmark: The concentration of mature practices in regions like the Basque Country suggests that the success of a Learning Factory is deeply linked to

a supportive regional ecosystem, characterized by a long-standing tradition of industry-school cooperation and early adoption of innovation.

In summary, Learning Factories are emerging as a vital bridge between theoretical education and industrial reality, though their long-term sustainability will depend on deeper integration with external stakeholders and the continued upskilling of the teaching workforce.

4.2. LEARNING FACTORIES IN OTHER EU PROJECTS

This subsection summarises the insights gathered from interviews with experts involved in European projects working on Learning Factories and related approaches. The objective was to capture a strategic and comparative perspective, complementing the school-level analysis with experiences from large-scale, multi-country initiatives. The interviewed projects include BRIDGES 5.0, SkillAIbility, EXAM4.0, VLF4EU, and LF4VET.

4.2.1. UNDERSTANDING OF LEARNING FACTORIES WITHIN EU PROJECTS

Across the interviewed projects, Learning Factories are consistently understood as integrated, close-to-real production or service environments that support experiential learning, skills development, and innovation. While terminology and implementation models vary, Learning Factories are generally framed as enablers of systemic learning, where technology, processes, organisation, and human factors are addressed together. Several projects explicitly emphasise the human-centred perspective of Learning Factories, aligning them with Industry 5.0 principles rather than purely technology-driven models.

Some EU projects propose evolutions of the traditional Learning Factories that are mainly focused on productivity and efficiency. As an example, SkillAIbility integrates, human factors (physical, cognitive, perceptual, and psychosocial) and explicitly targets vulnerable groups, including people with disabilities, low-educated workers, and ageing workers. Bridges5.0 proposes a methodology for transitioning to Learning Factory 5.0 settings by introducing human centricity, resilience, and sustainable activities, workplace analysis and human centric technology integration. LF4VET, in turn, proposes tools for coupling pedagogy and technology integration from a human-centric perspective.

The Learning Factories bridges the gap between technology development, skills foresight, and inclusive workforce empowerment.

4.2.2. RATIONALE FOR PROMOTING LEARNING FACTORIES

All interviewed projects support Learning Factories because they are seen as effective instruments to bridge education, training, and real industrial practice. Learning Factories are considered suitable not only for addressing skills gaps related to digitalisation, automation, AI,

and sustainability bur also to introduce industry 5.0 elements and values in educational settings. Projects highlight their capacity to combine technical skills with transversal competences, foster innovation-oriented mindsets, bring industrial organizational aspects into education and support closer collaboration between VET providers, higher education, research, and industry.

4.2.3.TARGET GROUPS

The target groups addressed by Learning Factories within these projects are diverse. While students in initial VET and higher education remain a core group, most projects also explicitly target workers and professionals through continuing VET (CVET) in upskilling and reskilling processes, as well as trainers, teachers, and researchers. Some initiatives also consider Learning Factories as platforms for experimentation and co-creation involving companies, particularly SMEs.

4.2.4.SECTORS AND PROFESSIONAL FIELDS

The projects mainly focus on industrial and manufacturing-related sectors, including advanced manufacturing, automation, robotics, AI-enabled production, and related engineering domains. However, several projects also stress the potential of Learning Factory approaches to be adapted to other sectors, especially where digital and green transitions are reshaping work processes.

4.2.5.IMPACT MEASUREMENT AND EVIDENCE ON SKILLS DEVELOPMENT

Most interviewed projects report that systematic and robust impact measurements are still limited or ongoing. While qualitative feedback, pilot evaluations, and case-based evidence suggest positive effects on skills development and learner engagement, comprehensive quantitative assessments and longitudinal studies are generally not yet available. Some projects have produced or plan to produce scientific or technical publications, but the overall evidence base is still emerging.

4.2.6.EXTERNAL FEEDBACK AND STAKEHOLDER INVOLVEMENT

Projects report varying degrees of engagement with companies and other stakeholders. In many cases, external feedback is collected through pilot activities, workshops, or co-creation sessions. Companies generally value the practical orientation and innovation potential of Learning Factories, but, as with VET schools, Learning Factories are not always explicitly recognised as a distinct concept by external stakeholders. Feedback often relates to specific tools, technologies, or training activities rather than to the Learning Factory as a holistic model.

4.2.7. METHODOLOGICAL AND TECHNOLOGICAL INNOVATIONS

Several projects introduce methodological innovations, such as project-based learning, challenge-based learning (CBL), human-centred design, competence-based assessment, and interdisciplinary collaboration. From a technological perspective, projects explore solutions including AI applications, data-driven production, cyber-physical systems, and, increasingly, virtual and hybrid Learning Factories. Virtualisation is seen as a key lever to improve accessibility, scalability, and cost-efficiency. The integration of human centric, resilience and sustainability is becoming a central activity.

4.2.8. SCALABILITY, TRANSFERABILITY, AND POLICY ALIGNMENT

A shared concern across projects is scalability and transferability. While Learning Factories are recognised as resource-intensive, projects are actively exploring modular, virtual, and network-based models to facilitate wider adoption. Alignment with European skills and VET policies, such as digital and green transitions, lifelong learning, micro-credentials, and Industry 5.0, is explicitly addressed, positioning Learning Factories as strategic tools for VET modernisation at European level. The collaboration among different agents of learning ecosystems, including schools, SMEs, industrial agents, policy makers is central for the development of the learning factories.

Overall, the interviews confirm that EU projects play a crucial role in experimenting with, structuring, and disseminating Learning Factory approaches, while also highlighting the need for stronger evidence, clearer evaluation frameworks, and broader awareness among stakeholders.

4.2.9. CONCLUSIONS FROM THE INTERVIEWS WITH EU PROJECTS

The analysis of expert interviews from major European projects (BRIDGES 5.0, SkillAIbility, EXAM4.0, VLF4EU, and LF4VET) indicates that Learning Factories are maturing from isolated technical labs into strategic instruments for European industrial policy. The following synthesized conclusions highlight the shift from a technology-first to a human-centric approach:

- Strategic Alignment with Industry 5.0: EU projects are leading the transition from "Learning Factory 4.0" (focused on automation and efficiency) to "Learning Factory 5.0." This evolution places a premium on human-centricity, sustainability, and resilience. By integrating psychosocial and cognitive factors into the production environment, these projects ensure that the digital transition remains inclusive and empowering for all worker profiles, including vulnerable and aging populations.
- A Bridge for the "Innovation Gap": Learning Factories are consistently identified as the missing link between technological foresight and practical workforce empowerment. They serve as a neutral ground where VET providers, SMEs, and research centers can co-create and experiment with AI-driven or cyber-physical systems before full-scale market implementation.
- Virtualization as a Key Driver for Scalability: Acknowledging the high resource intensity of physical factories, EU projects are increasingly pivoting toward virtual and hybrid models. This innovation is critical for the scalability of the concept, allowing a wider

network of VET schools and SMEs to access advanced training environments without the prohibitive costs of high-end physical hardware.

- Broadening the Target Audience: While traditionally focused on initial VET students, EU projects demonstrate that the LF model is uniquely suited for Continuous VET (CVET). They are becoming essential hubs for the upskilling and reskilling of the existing workforce, offering a safe yet realistic space for workers to adapt to the green and digital "twin transitions."
- Challenges in Impact Standardization: A significant finding is the current lack of longitudinal, quantitative data regarding the long-term impact of LFs on skills. While qualitative results are overwhelmingly positive, there is a clear call for the development of robust, standardized evaluation frameworks and competence-based assessment tools to validate the LF model at a policy level.
- Institutionalization through Ecosystems: Success at the European level is increasingly defined by the strength of the surrounding "learning ecosystem." The most effective projects are those that move beyond the "school-as-an-island" model, instead positioning the Learning Factory as a shared resource within a regional network of policy makers, industrial clusters, and educational institutions.

In conclusion, EU projects view Learning Factories as a cornerstone of VET modernization. The shift toward modular, human-centered, and digitally-accessible models suggests that the future of the Learning Factory lies in its ability to be both a technological sandbox and a social inclusive space for lifelong learning.

4.3. PRELIMINARY CONCLUSIONS FROM THE FIELD RESEARCH

Based on the initial analysis framework and the synthesis of interview data, the field research leads to the following overarching conclusions.

First, the interviews largely confirm the findings of the desk research. In particular, Learning Factories are validated as an effective response to skills needs in advanced manufacturing, supporting experiential learning, the development of transversal skills, and a closer alignment between VET provision and industry requirements.

Second, the field research highlights additional dimensions that were not fully addressed in the desk research. These include:

- The value of Learning Factories for inclusion, especially for learners with disabilities, through adaptable learning environments, task differentiation, and the combination of physical and digital learning spaces;
- The relevance of Learning Factories for worker training and continuing VET (CVET), extending their role beyond initial VET to the upskilling and reskilling of the existing workforce;
- The significant potential for virtualisation, including virtual and hybrid Learning Factories, which increase accessibility, scalability, and cost-effectiveness, while supporting remote learning and collaboration.

- A more detailed and evidence-based articulation of these conclusions is presented once the interview data has been fully collected, coded, and analysed, enabling a robust comparison between desk research findings and field-based insights.

5. CONCLUSION AND OUTLOOKS

This report set out to analyse the role and potential of Learning Factories in VET by combining desk research and field research. By integrating evidence from project reports, academic literature, and interviews with experts and practitioners, the study provides a consolidated, though exploratory, assessment of Learning Factories as an educational and organisational approach.

The desk research indicates that Learning Factories are a promising response to the evolving skills needs of advanced manufacturing in the face of the twin transitions. By replicating real production environments and processes, Learning Factories help to reduce skills mismatch between VET provision and labour market demands. They allow learners to engage with technologies as they are actually used in companies, rather than as isolated tools, thereby bridging the gap between education and work.

Learning Factories also emerge as a relevant and effective mechanism for introducing new digital and green technologies into VET schools, even in contexts where technological adoption in industry is uneven. Their structure supports gradual and contextualised integration of innovation, aligning well with the realities observed in companies. At the same time, Learning Factories play a key role in keeping teachers' knowledge and skills up to date, as they require educators to work continuously with current technologies, processes, and pedagogical approaches.

A strong alignment is observed between the Learning Factory concept and the LCAMP skills framework, particularly with regard to the balance between foundational skills, transversal competences, and context-specific specialisation. Learning Factories reproduce the entire value chain of production, enabling learners to understand digitalisation as a means to support production objectives rather than as an end in itself. This holistic approach ensures that students develop a systemic understanding of production, work organisation, and technology.

Moreover, Learning Factories expose learners to non-technological dimensions of production, such as organising work, dividing tasks, coordinating roles, making decisions, and solving problems. This contributes to a form of competence development that is close to real industrial practice, avoiding artificial or decontextualised learning situations. The active learning methodologies typically adopted in Learning Factories further support the development and, when appropriate frameworks are in place, the assessment of transversal skills such as teamwork, communication, adaptability, and problem-solving.

The field research largely confirms these findings. Interviews with experts and practitioners validate Learning Factories as an effective approach to addressing skills needs in advanced manufacturing, strengthening experiential learning, and improving alignment between VET and industry. At the same time, the field research brings additional perspectives that extend the conclusions of the desk research.

In particular, the interviews highlight the potential of Learning Factories to support inclusion, especially for learners with disabilities, through adaptable environments, differentiated tasks,

and the combination of physical and digital learning spaces. They also underline the relevance of Learning Factories for worker training and continuing VET (CVET), positioning them not only as tools for initial VET, but also as infrastructures for upskilling and reskilling the existing workforce. Furthermore, the field research points to the significant potential for virtualisation, including virtual and hybrid Learning Factories, which can enhance accessibility, scalability, and cost-effectiveness, while supporting remote learning and collaboration.

At the same time, several limitations must be acknowledged. The size of the sample analysed in both desk and field research is relatively small, and robust, standardised impact measurements are still largely missing. Many findings are therefore based on qualitative evidence, professional judgement, and individual perceptions. Given that Learning Factories are still an emerging approach in many VET systems, it is too early to draw definitive conclusions about their long-term impact. Further research is needed, including larger-scale studies, longitudinal analyses, and the development of shared indicators to assess educational, organisational, and socio-economic outcomes.

Despite these limitations, the results of this study point to a high potential for transferability of the Learning Factory approach beyond advanced manufacturing. The underlying principles, learning by doing, integration of technology into real processes, holistic understanding of value chains, and development of transversal skills, are highly relevant for other VET sectors. Promising areas include, for example, the food industry and food processing, logistics, energy and sustainability-related sectors, healthcare technologies, and other production- or process-oriented fields where quality, safety, efficiency, and innovation are critical.

In conclusion, Learning Factories represent a promising, flexible, and future-oriented approach for VET, capable of supporting digital and green transitions, fostering inclusion, and strengthening the link between education and the world of work. While further research and evidence are required, the findings of this report suggest that Learning Factories can play a strategic role in the modernisation of VET across Europe.

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7. ANNEXES

7.1. ANNEX 1 INTERVIEW TEMPLATE FOR VET SCHOOLS

Questions regarding Learning Factory concept implementation for Schools:

Section 1: Definition & Strategic Vision

Goal: To understand how the school integrates the LF into its identity.

1. **Terminology & Concept:** ¿How does your institution define a "Learning Factory"? Is there a specific internal name used for this facility (e.g., iLab, Teaching Factory, Smart Workshop)?
2. **Investment Drivers:** ¿What was the primary motivation for the school to invest in a Learning Factory? (e.g., modernizing the image of VET, aligning with Industry 4.0, responding to local industry demand).
3. **Methodological Evolution:** ¿Prior to the LF, did the school utilize active learning frameworks (PBL, Experiential Learning, Challenge-Based Learning)? How has the LF changed or enhanced these existing practices?

Section 2: Technical Infrastructure & Facilities

Goal: To map the physical and digital assets of the school.

4. **General Facilities:** ¿Beyond the Learning Factory, what other specialized workshops or labs does the school maintain? (Please provide a brief overview of the technical ecosystem).
5. **LF Manufacturing Processes:** ¿Which specific manufacturing or industrial processes are replicated within the LF? (e.g., assembly, CNC machining, logistics, quality control).
6. **Technology Stack:** ¿Which key technologies are integrated into the LF? (e.g., Industrial IoT, Collaborative Robots/Cobots, Additive Manufacturing, AGVs).
7. **Digitalization & Digital Twins:** ¿Does the facility incorporate Digital Twins? If so, are they twins of specific machines, entire production lines, or the logistical flow?

Section 3: Academic Integration & Synergy

Goal: To understand how students and the community interact with the LF.

8. **Program Integration:** ¿Which specific study programs or departments utilize the Learning Factory? (e.g., Mechanical Engineering, Mechatronics, ICT, Industrial Management).
9. **Cross-Disciplinary Use:** ¿Does the LF facilitate collaboration between different departments (e.g., Business students working with Engineering students)?
10. **External Validation:** ¿What feedback have you received from industry partners or local companies regarding the quality of training provided via the LF? Does it meet their recruitment standards?

7.2. ANNEX 2 INTERVIEW TEMPLATE FOR OTHER EU PROJECTS

Questions regarding Learning Factory concept implementation for other EU projects.

Section 1: Conceptual Framework & Motivation

Goal: To understand the "what" and "why" behind their specific model.

1. **Definition & Scope:** ¿How is the "Learning Factory" concept defined and operationalized within your project? (e.g., is it a physical lab, a digital twin, or a decentralized network?)
2. **Strategic Value:** ¿What were the primary drivers for choosing the LF model over traditional vocational or academic training methods?
3. **Unique Selling Point (USP):** What specific problem or "innovation gap" does your Learning Factory aim to bridge?

Section 2: Target Audience & Industry Alignment

Goal: To identify the stakeholders and the economic sectors involved.

4. **Target Groups:** ¿Who are the primary beneficiaries of your LF? Please specify the approximate distribution between:
   o HEI Students (Undergraduate/Postgraduate)
   o VET Learners (Vocational Education)
   o Industry Professionals (Upskilling/Reskilling)
   o Researchers & PhD Candidates
5. **Sectoral Focus:** Which industrial sectors or professional families (e.g., Industry 4.0, Green Construction, Agritech) does your LF serve?
6. **Competency Mapping:** ¿Which specific "Future Skills" (technical, soft, or green skills) are prioritized in your curriculum?

Section 3: Impact, Validation & Feedback

Goal: To gather evidence of success and lessons learned.

7. **Impact Assessment:** ¿What methodologies or KPIs do you use to measure the impact of the LF on skill development? (e.g., pre/post-testing, longitudinal studies, employability rates).
8. **Stakeholder Feedback:** ¿How do external partners (SMEs, industrial clusters, or policy-makers) perceive the value of the LF? Have they reported any tangible benefits to their production or innovation capacity?

9. **Evidence & Publications:** ¿Could you share links to impact reports, peer-reviewed papers, or case studies resulting from your LF implementation?

Section 4: Scalability & Sustainability

Goal: To understand the long-term viability of the project.

10. **Financial Sustainability:** ¿How do you plan to maintain the LF after the EU funding period ends? (e.g., service fees, industry memberships, institutional integration).
11. **Transferability:** ¿In your experience, what are the "must-have" conditions for successfully replicating your LF model in another region or sector?

7.3. ANNEX TEMPLATE FOR DESK RESEARCH

Section 1: Document Identification and Context

Goal: To classify the source and understand its relevance within the Advanced Manufacturing ecosystem.

1. **Bibliographic Reference:** (Title, author, year, document type: project report, academic paper, public policy).
2. **Geographic Scope:** (Country, region, or European level).
3. **Link to LCAMP:** (How does it relate to work packages WP2, WP3, WP5, or WP6?).

Section 2: Analysis of Skills Needs

Goal: To identify the labor market trends mentioned in the document that justify the use of Learning Factories.

4. **Transformation Trends:** What weight is given to digitalization and the green transition (twin transitions)?
5. **Job Evolution:** Are new profiles mentioned (e.g., data analytics) or the evolution of existing roles (e.g., maintenance 4.0)?
6. **Prioritized Skills:**

   o Technical/Foundational: (Necessary base knowledge).
   o Transversal: (Problem-solving, adaptability, communication).
   o Digital/Green: (IoT, AI, energy efficiency, carbon footprint).

Section 3: Learning Factory (LF) Conceptual Framework

Goal: To extract the theoretical definition and pedagogical objectives proposed by the source.

7. **Definition of LF:** How does the document describe a "Learning Factory"? (e.g., semi-industrial environment, digital ecosystem).
8. **Pedagogical Methodology:** What active learning methodologies are proposed? (e.g., PBL, challenge-based learning, experiential learning).
9. **Value Chain Integration:** Does the document emphasize a holistic view of processes versus learning isolated tools?

Section 4: Infrastructure and Enabling Technologies

Goal: To map the technological assets and industrial processes that the literature considers critical.

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10. **Key Technologies:** (Collaborative robotics, sensors, PLCs, additive manufacturing, AGVs).
11. **Digitalization and Digital Twins:** Is the use of Digital Twins analyzed for simulation or monitoring?
12. **Replicated Processes:** (CNC machining, assembly, logistics, quality control).

Section 5: Impact, Inclusion, and Sustainability

Goal: To gather evidence of success and the approach toward Industry 5.0.

13. **Impact Measurement:** Are key performance indicators (KPIs), longitudinal studies, or competency assessment frameworks cited?
14. **Human-Centric and Inclusive Approach:** Is adaptation for people with disabilities or aging workers mentioned?
15. **Virtualization Potential:** Does the document analyze scalability through virtual or hybrid LFs?

Section 6: Conclusions and Inferred Insights

Goal: To synthesize how this document contributes to closing the gap between education (VET) and industry.

16. **Alignment with Competency Frameworks:** (e.g., LCAMP skills framework).
17. **Transferability:** Which additional sectors are suggested? (e.g., food, health, energy).
18. **Identified Limitations:** (Lack of data, high costs, need for teacher training).

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