D 4.3
Knowledge delivery mechanisms towards a knowledge-intensive industrial workforce (v1.1)

Action acronym	ConnectedFactories 2
Action Full Title	Global-leading smart manufacturing through digital platforms, cross-cutting features and skilled workforce
Grant Agreement Number	873086
Instrument	CSA: Coordination and Support Action
Project coordinator	VTT
Deliverable Number	D4.3
Deliverable Title	Knowledge delivery mechanisms towards a knowledge-intensive industrial workforce
Lead Beneficiary	LMS
Work package	4
Work package leader	LMS
Dissemination level[1]	Public
Type[2]	R
Due date according to DoA	31 May 2022
Actual submission date	13 June 2022
Main editors and contributors:	LMS (lead)
	VTT, FPM, CEA, Fraunhoefer, TNO, MTC, I4.0, IMR

1 PU: Public, CO: Confidential, only for members of the consortium (including the Commission Services)
2 RE: Report, OT: Other; ORDP: Open Research Data Pilot

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 873086.

VERSION MANAGEMENT			
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Author(s):		Kosmas Alexopoulos	LMS
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Reviewed by:			
Revision No.	**Date**	**Description**	**Author**
0.1	16/12/2021	Draft outline	LMS
0.2	19/01/2022	Sections assignments to WP3 partners	LMS
0.3	20/03/2022	Input received for several chapters	VTT, FPM, CEA, Fraunhoefer, TNO, MTC, I4.0, IMR
0.4	15/04/2022	State of the art – WP2	LMS
0.5	10/05/2022	EU level – chapter 3.1	LMS
1.0	31/05/2022	Compiled version	LMS
1.1	10/06/2022	Address comments received by VTT	LMS

Abbreviations and acronyms

TERMS, ABBREVIATIONS AND ACRONYMS	
AI	Artificial Intelligence
AM	Additive Manufacturing
AR	Augmented Reality
DEP	Digital Europe Program
EDIH	European Digital Innovation Hubs
EIT	European Institute of Technology
EU	European Union
IT	Information Technology
KDM	Knowledge Delivery Mechanism
LF	Learning Factory
L&T	Learning and Training
MOOC	Massive Open Online Course
TF	Teaching Factory
VET	Vocational and Education system
VR	Virtual Reality
WP	Work Package

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Executive Summary

The strategies for upskilling and reskilling for competitiveness, growth and jobs in manufacturing will be very critical. However, the delivery mechanism models that contribute to the task of lifelong learning need to be investigated. One of the key objectives of the Connected Factories II (CFII) project is to investigate the demand for new skills within a manufacturing company's labour force that traditionally weren't required. Aspects such as life-long learning and new teaching paradigms have become increasingly important. This deliverable focuses on identifying the associated trainings, courses and delivery mechanisms for industrial workers/managers that are available and that match the skills that are required to progress along the ConnectedFactories pathways. In order to achieve this objective CFII is looking into stakeholder's offerings in European, National and regional ecosystems, such as national training programs, European Skills Development programs and manufacturing community driven learning and training content delivery mechanisms.

The exploration of knowledge delivery mechanisms and business models for upskilling and reskilling has indicated that several approaches are employed from both the business and the technical or methodology point of view. From technology and method point of view the following knowledge delivery systems/mechanisms have been analysed: Vocational Training, MOOC and Learning and Training online nuggets, Games and Gamification, Virtual and Augmented Reality, Teaching and Learning Factories, on the job training.

From business point of view there are several entities offering lifelong learning (upskilling and reskilling) services such as EDIHs, Competence Centers, Digital Europe Program and the education pillar of EIT-Manufacturing create a new set of L&T opportunities that are combined with a holistic set of services to companies, including testing of equipment and technical services, business creation and incubation as well as networking and access to markets and ecosystems.

Looking at the current landscape in L&T knowledge delivery mechanism and the needs for upskilling and reskilling in advanced manufacturing it can be concluded that more support to innovative life-long learning approaches is required together with supporting advanced technology developments such as AR/VR and their L&T applications in manufacturing. EU should also take stock of the EDIH network in order to promote skills development and create synergies with manufacturing focused initiatives such EIT Manufacturing and Made In Europe manufacturing partnership of EFFRA with the European Commission under the Framework Programme 'Horizon Europe'.

In chapter 2 the document considers several knowledge delivery mechanisms such as MOOCs, life-long learning and hands-on practices, as well as novel paradigms such as the Teaching Factory and others. Chapter 3 investigates European and National level initiatives offering education and training for Industry4.0 and Industry5.0. Chapter 4 discusses the findings and assess the application of different knowledge delivery mechanisms for skills and training in advanced and digital manufacturing.

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1 Introduction

The strategies for upskilling and reskilling for competitiveness, growth and jobs in manufacturing will be very critical. However, the delivery mechanism models that contribute to the task of lifelong learning need to be investigated.[3] A set of novel knowledge delivery mechanisms have been identified within the context of this deliverable. Further to this identification a review of these mechanisms will also take place in accordance with the new job requirements identified in Task 4.1 and Task 4.2.

In chapter 2 the document considers several knowledge delivery mechanisms such as MOOCs, life-long learning and hands-on practices, as well as novel paradigms such as the Teaching Factory and others.

Chapter 3 investigates European and National level initiatives offering education and training for Industry4.0 and Industry5.0.

Chapter 4 discusses the findings and assess the application of different knowledge delivery mechanisms for skills and training in advanced and digital manufacturing.

2 Knowledge Delivery Mechanisms – State of the art

Manufacturing comprises one of the main economic, wealth sectors of a country; thus, high importance is paid in innovation and research on that field (Hanuschek, A.E. et al., 2007). Manufacturing has entered a new era of rapid, technological advances and various, novel techniques. Engineers and workers have to deal with a never-ending demand for new skills that Industry 4.0/5.0 asks for. Life-long training and skills enrichment seem necessary, while the educational and vocational system find it hard to cope with these challenges. Manufacturing is a subject that cannot be treated effectively only inside a classroom, whilst industry can only evolve through the adoption of new research results. Current skill endorsement cannot keep the pace with the technological advances and on-the-job training becomes even scarcer, since manufacturing companies look for already skilled and developed engineers. Therefore, special significance has to be paid on innovation and further development of the knowledge delivery mechanisms on manufacturing. Traditional techniques, such as on-the-job training, vocational training have paved the way for more innovative ideas like teaching factories, learning factories, massive open online courses, learning nuggets and educational games. Online and off-site education seems to have become the trend in skills training. An overview of the mentioned knowledge delivery techniques is provided in the following subsections, followed by their current challenges and their successes in the manufacturing, education sector.

2.1 Vocational training

Both economic performance indicators and the results of qualitative innovation research show that innovation does not stop at the doors of R&D departments. It arises in the interplay between a wide range of disciplines and departments, right across the product lifecycle. And here we find not just employees with academic qualifications, but also those trained in the dual system. Thus employees with technical or science-oriented vocational qualifications play a key role in innovation projects, within R&D departments, as skilled

[3] Skills for Industry, Online Training, Promoting Opportunities for the Workforce in Europe, European Union 2019

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workers in prototype building, in the fields of testing or implementation, as draftsmen and draftswomen in construction, or as laboratory technicians in various specialist areas (Pfeifer S., 2015).

Vocational training refers to instructional programs or courses that focus on the skills required for a particular job function or trade. In vocational training, education prepares students for specific careers, disregarding traditional, unrelated academic subjects. Vocational training has been adopted mostly for technical professions without neglecting necessary academic knowledge (Solga S. et al., 2014). Orchestration and integration of a successful vocational and education system (VET) has been a challenge for most countries. Germany has been a pioneer of the dual (vocational and educational) system, with most nations being willing to implement it on their VETs. Germany's novel system is based on developing the trainee according to the following principles: a) the individual dimension: referring to the role of vocational training in developing the skills individuals need to meet challenges on the job as well as in other aspects of their life, b) the social dimension: referring to vocational training as a means of promoting the social integration of the younger generation, both in the workplace and in society at large and c) the economic dimension: referring to the role of vocational training in ensuring a high level of economic, business and individual productivity (Euler D., 2013).

Other countries with successful and impactful implementations of dual systems are the Netherlands, Denmark and Norway, Luxembourg, England. The Greek vocational system can be tracked down to two categories: a) Institutions of Vocational Training (IEK) referring to vocational organizations dedicated for the development of professionals in the tertiary education (18 + years), b) TEEs that can be described as a second type of schools of the upper secondary education system, focusing on the introduction and development of professional skills to students. Both types of vocational institutions provide certificates of expertise to their candidates upon evaluation (Vretakou V. et al., 2013).

In order to cope with the never-ending demands of Industry 4.0, vocational training needs to integrate as many new qualifications as possible. Some of them can be: approaches of Web 2.0 in manufacturing, Cyber-Physical Systems introduction, Internet of Things and Big Data techniques, Robotic arms in production and advanced manufacturing processes, Assembly and Operator Assistance via edge approaches like AR/VR and Mixed Reality (Pfeifer S., 2015). Integration of these novelties is still difficult and premature in vocational training; thus, this topic is and will continue being of high priority for educational institutions all around the globe.

2.2 Massive Open Online Course–MOOC and Learning and training nuggets

MOOC, an acronym for massive open online course, has been nearly ubiquitous in recent discussions about online education and distance learning (Hew K. F. et al., 2014). MOOCs provide an affordable and flexible way to learn new skills, advance your career and deliver quality educational experiences at scale. The term MOOC was originally used by George Siemens and Stephen Downes in 2008, and since then has gained popularity in the USA especially when Sebastian Thrun, a Stanford professor offered an artificial intelligence course for free (Hu H. et al.,2013). The MOOC is a technology-based learning format that encourages open education. MOOCs are open in the sense that they are free from the geographical boundary of physical classrooms, free from physical boundaries that limit course size, free from temporal boundaries in that their content can be accessed on demand as often as desired given a working Internet connection, free from entry requirements in that they rarely have formal prerequisites as barriers to entry, allowing learners of all skill levels to explore content Dodson M. N. et al., 2015). Cost is not a constant variable since some MOOCs are offered as free while others demand a certain fee.

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As Karnouskos (et al. 2017) states, the most important assets that an employee may acquire from a MOOC, are the following: culture, knowledge, leadership, innovation, communication and technology apprehension. Main representatives and initial pioneers on the sector may be considered edX and Coursera. The content of a MOOC can be almost anything and any subject that is taught in a university or an Industrial training program. Among others the following subjects have been observed in MOOCs: a) Electronics, b) Operations Management, c) Sociology, d) Artificial Intelligence, e) Introduction to Economics etc.

Learning systems for assisting newcomers, interns or just giving a first glimpse of a topic to a field enthusiast have been of high priority for most educational institutions and industrial companies. Among others, the European Institute of Innovation and Technology (EIT) has been a pioneer in knowledge delivery mechanisms such as the learning paths and nuggets.

As Mayrhofer states (et al., 2021),EIT Manufacturing has been and still is currently developing a pan-European learning platform with the vision to create an “on-the-job learning assistance system”. The online learning platform strives to provide digital, modular, and interactive learning content dubbed “learning nuggets”. A learning nugget is an online learning unit with a specific topic to acquire competences with a maximum time expenditure of 30 minutes. A learning path consists of several learning nuggets sorted into a “path” to acquire competences (Kloosterman H. J. et al., 2019). A learning path is a logically sequenced and complete set of learning content to achieve competences. To create the learning paths, the main competences that describe whole groups of competences need to be defined (Bardy S. et al., 2021).

The learning nugget approach has reached a level of maturity, adequate enough to be implemented in engineering’s education pipeline. Tzavara (et al., 2021) and Mayrhofer (et al. 2021) adopted the learning nuggets and paths technique and implemented for educational purposes on the cobot sector (collaborative robots). In particular, Mayrhofer introduced cobots ton audience through learning nuggets, in an extensive and thorough skills acquisition program, while Tzavara stressed the possibilities of human and robot collaboration in assembly tasks. Bardy introduced AI to human workers via learning nuggets, involving predictive maintenance, quality inspection and ethics.

2.3 Games and gamification

Nowadays, the increasing competition between manufacturing companies compels them to reorganize their human resources seriously by recruiting multi skilled engineers and technicians that can face the challenges of Industry 4.0. Such developed and accomplished professionals are hard to be found, but even in that case introduction and novice training is necessary so as they can follow the norms of a new company. Several efforts have been made to design new learning methods in order to train novice engineers about the production concepts in diverse manufacturing areas as well as teaching engineering students in novel ways to transfer real world applications to educational class. Serious games have been established as a new and promising instructional method in different areas, and recently they have also appeared in manufacturing and engineering education (Pourabdollahian, B. et al., 2012).

The term 'serious games' was first used in 1970 by CLARK C. ABT. He defines serious games as "games that have an explicit and carefully thought-out educational purpose and are not intended to be played primarily for amusement (Djaouti D. et al., 2012). This does not mean that serious games are not, or should not be, entertaining “Digital learning games can generally be characterized by six features: interactivity, multimediality, involvement, challenge, social experience and reward. These features and the options

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available for shaping them enable learning results that are not achievable with other media at all or only to a very limited extent (Gorke M. et al., 2017).

Serious games in the manufacturing sector have become mature enough in order to be implemented for educational purposes. Hauge J. B. (et al., 2012) has been involved with the evaluation of two serious games for teaching engineers, COSIGA and Beware. The former is a multi-media, multiplayer computer-based simulation game which was designed to support the education of engineers in the use of Concurrent Engineering for new product development. It realistically simulates the collaborative and co-operative process of product development, with an emphasis on a concurrent engineering approach. The latter, Beware, is a game developed to increase the understanding and awareness of risks in enterprise networks and to improve players' skills on risk management in enterprise networks. Nikolakis (et al., 2020) presented an assistive game approach for operators' support in shop floors with the aid of machine learning. Badurdeen F. et al., 2010) has made a survey on lean manufacturing games, addressing many of the most influential games that have been developed so far. Among others: the Beer game of MIT in 1963, VEEBOT involving product development of LEGO cars, multiple Ship Repairing simulation games and Circuit Board games.

2.4 Virtual and Augmented reality

The issue of training operators in the use of machinery is important in many manufacturing companies. Training on the use of machinery is necessary in different situations: when the machinery is new, when the operator is newly hired, when some functions of the machinery are rarely used by the operator, who easily forgets the sequence of use (for example, how to perform actions that are carried out only in emergency situations). The question of training on the use of machinery is also a necessary activity in contexts beyond the industrial one. An example concerns training that is mandatory for the use of machinery and equipment in university laboratories. On the other hand, on-the-job training has many negative factors. One factor to consider is that training may involve high costs. In fact, training is typically provided by instructors, who must be experienced and skillful. Instructors are typically key employees who have to devote their time to train new workers, to the detriment of their activities in the company. When training is provided onsite, the operators actually use the machinery, which is idle during the training period, and it cannot be used for profitable activities. Besides, training may require the use of physical materials and consumable, which are discarded when finished. Thus, this may generate considerable expenses. An approach that may contribute overcoming these negative factors and bringing benefits to companies for what concerns the matter of operators training is using Virtual Reality (VR) and digital simulations. VR training has proved to be effective in diverse contexts, and to revolutionize the way people are being trained in healthcare, business, military, engineering, and many other industries (Bordegoni et. al. 2021). Training performed in VR has proved to have many benefits, and for this reason, it has been used by an increasing number of manufacturing companies. VR has been used for training operators in traditional machine shop operations (Chryssolouris et. al. 2002). In a similar manner VR has been employed for training operators in their interaction with robotic systems (Karagiannis et. al. 2020).

In recent years, AR is being increasingly applied to education and training concepts, with high potential on strengthening the motivation of learners and optimizing the learning process (Bologna et. al. 2022). AR provides various potentials under the perspective of teaching and training, due to the major benefits in terms of interactivity, safety on equipment operation, low-cost training and virtual experience that is impossible in a real environment (Sorko and Brunnhofer, 2019). In Siatras et. al. (2019) users from both industry and academia can simultaneously visualize and analyze process information within the AR environment, in the

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foreground of the physical or the digital equipment respectively. Further on, the application assisted the assembly operations of the process equipment, using animated holographic components for creating a realistic display of the of the assembly steps. The potentials of AR to face current challenges in production, show state-of-the art applications and present an own developed AR application to support the employee with their work tasks are discussed in Eder et. al (2020), with the application introduced, employees are provided with real-time data from their machinery, which is displayed in their field of vision. In addition, the application enables the processing of more complex and non-repetitive tasks that would otherwise require additional know-how or personnel.

2.5 Teaching factory

The Teaching Factory (TF) concept has its origins in the medical sciences discipline and specifically in the paradigm of the teaching hospitals, namely the medical schools operating in parallel with hospitals (Mavrikios D., et al., 2013). It aims to incorporate the learning and working environment from which realistic and relevant learning experiences arise. Two-way knowledge interaction is the ultimate goal of the technique, based on two educational channels: a) the “factory to classroom” and the “academia to industry”. The first refers to the experiences that industrial experts can transmit to the students through their on-site expertise. Day-to-day challenges and production difficulties might not be very clear to students from their academic knowledge. The real-life production site has to be used for teaching purposes in order to enhance the teaching activity with that of knowledge, existing in the processes of every day industrial practice. Application integration is also considered one of the main issues that production has to face and that the “classroom” cannot adequately recreate. On the other hand, students and research engineers have a better perception of the innovative techniques that arise in the manufacturing section. The TF concept might work as a retraining/skills enrichment method for industrial operators and engineers. Another encounter that industrial sites face is the high cost and time-consumption that manufacturing initiatives demand in order to be implemented on their actual production. The Teaching Factory can be a useful facility for the validation of such concepts, while closing the gap between production innovation and education.

2.5.1 Teaching factory concept description

The “factory to classroom” operation scheme (see Figure 1) is based on the adoption of an industrial project. Field experts address the current issues that are faced in production, in combination with useful production details and specifications that render the production pipeline more understandable to the students. Initial production familiarization is being followed by the assignment of a specific task to the students. The task usually refers to the modernization of a traditional process that is being performed during production or the integration of a novel, promising idea that can revitalize the manufacturing pipeline or the product lifecycle. The industrial project is addressed through a weekly cycle of sessions, comprising supporting classes, project work and live interactions with the factory. Constant communication with the industrial personnel is utilized in order to investigate and develop a solution that follows the logistics and rules of the partner. The supporting classes are moderated by an academic supervisor, who is also responsible for triggering the discussions and providing guidelines in search of solution paths.

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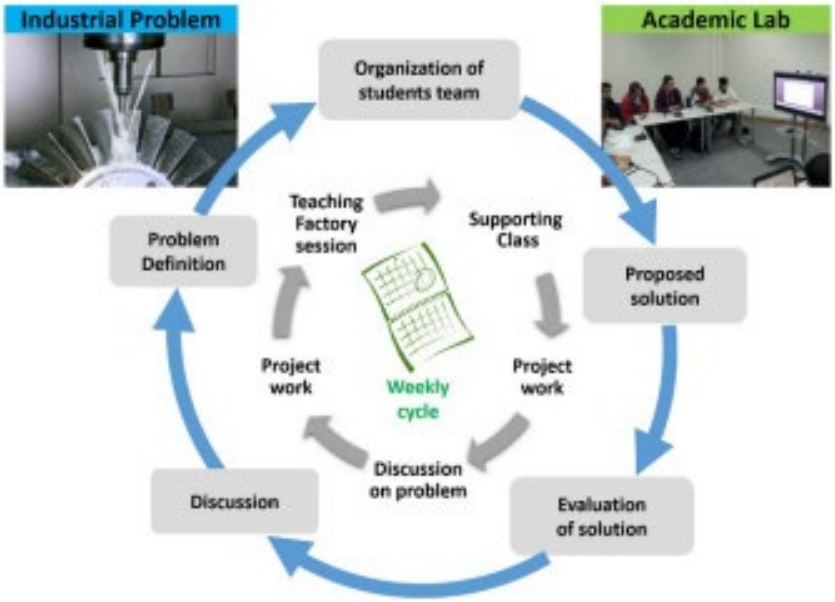

Figure 1: The Teaching factory framework

After the occasion of multiple didactic and development sessions, the solution has been completed by the students. Solution presentation follows, indicating the strengths and weaknesses of it. Since development is led by off-the-edge techniques of the manufacturing sector, students have the opportunity to demonstrate these novelties to the industrial personnel, while field experts can evaluate the applicability and integration possibility of these ideas. This step appears as the most vital to the process, since that is when students come to face the difficulties that cannot be recreated “inside the classroom”, while industrial operators acknowledge the difficulties that new, inexperienced engineers face in their pursuit of a manufacturing career. Skills and on-the-job experience are hard to be acquired, meaning that tolerance and help has to be offered to newcomers.

2.5.2 Implementations of the Teaching Factory concept

The Teaching Factory (TF) framework has found multiple applications in the recent years. The TF concept has its origins in the medical sciences discipline and specifically in the paradigm of the teaching hospitals, namely the medical schools operating in parallel with hospitals. TF has emerged as a promising paradigm for integrating the learning and working environments and operates as a bidirectional knowledge communication channel "bringing" the real factory to the classroom and the academic lab to the factory (Mavrikios et. al. 2029). **On construction equipment**: A real-life pilot was conducted among university students and engineers working at a construction equipment factory in Europe. The industrial problem addressed in this “factory-to-classroom” pilot was the line balancing of a new production area for the construction equipment factory. The factory produces wheel loaders among other construction equipment products. The project comprised of two main subtasks. On the first task, students managed to define the workload strategy for each station of the welding line of a wheel-loader’s rear frame and investigate the effects of the workload on the system’s output in relation with the system’s sensitivity to any deviations in the processing times. Furthermore, within the context of the industrial problem, the students had to plan the material flow in the line in terms of human resources and equipment. They provided an understanding of the optimal positions of the different component types, depending on the variability of the product, while defining the location of the handling equipment and human resources in order for the material feeding

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process to be carried out. The students managed to identify bottlenecks creating disturbances in the assembly line of the production area. The suggestions of the team led to an updated production to prevent bottlenecks. (Rentzos L. et al., 2014).

On machine processes: Stavropoulos of LMS (et al., 2018) led the supervising activities for a Teaching Factory dedicated to the design of a MultiTechnology Platform (MTP) that combines a milling working centre with a robotic arm equipped with a laser head. RWTH Aachen had accepted the role of the industrial partner in this collaboration. The students, separated in two teams, had to design the swivel table in collaboration with the machine shop where the MTP would be installed. The industrial requirements were given in the form of specifications regarding the static compliance, thermal load and dynamic compliance of the final product. The Teaching Factory followed a 5-cycle schedule. By the end of the project both teams had designed a product that fulfilled the desired specifications provided by the partner, encountering the challenges that machine development faces and the necessity for adaptation in contrast with initial planning.

On Industrial Automation: A reverse knowledge transfer channel has been observed in Chryssolouris' (et al, 2016) research. A Teaching Factory was orchestrated according to this idea, involving a company producing automation and control equipment. The content of the pilot was to demonstrate the academic partner's research work on mobile robots and flexible robotic cells, while investigating the way that they could apply this knowledge to industrial problems. Two demonstrators were selected, a car chassis robotic welding and a razor handling cell. The delivery mechanisms for this pilot were mainly live videos and audio interactions with the engineering office from the academic lab through an advanced ICT configuration. The students and the teaching staff were located in the lab. Various live cameras setups were used to show the lab demonstrators. At the same time, a presentation was shared through a web-conferencing tool, showing details.

2.6 Learning factory

In a TF setting there is bilateral, usual remote collaboration, between industry and academia. In TF the factory environment (e.g. equipment, problems, practices) are brought to the classroom via ICT tools, and students are educated on new topics without the need to have physical access to equipment since the experience of working with industrial equipment is adequately delivered through ICT methods. In the Learning Factory (LF) setting, the educational institute is equipped with production equipment, usually advanced ones, and this provides the opportunity to students and professionals to be educated on this equipment by visiting physically, or sometimes virtually, the LF premises. In essence TF and LF can complement each other and can both be offered simultaneously.

Initiatives such as the LF have sought to develop experiences through the inclusion of industrial projects under the active learning approach on the curriculum of some engineering programs. Preliminary studies have shown a better performance in the development of skills and acquisition of knowledge than traditional approaches. The LF concept was mentioned for the first time in an initiative of a group of universities from the United States in 1995. Since then, there have been multiple proposals of Learning Factories, while institutions such as the European government have adopted the LF as an official initiative for the education of engineers (Baena F. et al., 2017).

A learning factory in a narrow sense is a learning environment specified by: a) processes that are authentic, include multiple stations, and comprise technical as well as organizational aspects, b) a setting that is changeable and resembles a real value chain, c) a physical product being manufactured, and d) a didactical

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concept that comprises formal, informal and non-formal learning, enabled by own actions of the trainees in an onsite learning approach. In general terms, the primary purpose of learning factories is "Learning" in a "Factory" environment (Abele E., et al., 2017).

2.6.1 Learning Factory implementations

The activities of the LPS Learning Factory at Ruhr University of Bochum are characterized by the interfaces between human beings, technology and organizations. The LPS operates a pilot factory in which the theoretic concepts developed are implemented and technology demonstration and transfer to industry are promoted. The learning factory LSP for streamlined products and production management, operated by the Institute for Machine Tools and Industrial Management (TU Munich), focuses on Lean Production principles (Bender B. et al., 2015). Learning Factories have not been limited to only academic institutions, since industrial companies have adopted the initiative. An example is the Chrysler World Class Manufacturing Academy in Michigan, USA (UAW-Chrysler National Training Centre) which features both full-scale physical learning factory facilities for experiential learning related to their required manufacturing competencies as well as supportive on-line learning courses that can be accessed remotely by their employees.

In the Greek, R&D sector, LMS has led the activities of educational initiatives such as the LF. Mourtzis (et al., 2020) proposed the design and development of a flexible manufacturing cell under the concept of the LF paradigm for the education of 4.0 engineers. The practical implementation of the proposed concept was realized through the case of a manufacturing cell, comprising of a 3D-printer, a robotic arm and a CNC milling machine. Therefore, three groups of students were assembled, each responsible for one of the already mentioned subtasks of the project. The proposed cell was finally tested in vitro, in order for the students to acknowledge the integration difficulties and practical challenges of a theoretical approach.

Mourtzis and Siatras (et al., 2020) introduced a framework enabling collaborative product design based on AR, which acted as the digital thread for connecting engineers to customers. A team of students in engineering faculties was gathered, responsible for the design and development of a Cloud platform for supporting file exchange and storage. The Cloud platform can be realized as the communication layer between the stakeholders. In addition, an end-user application for the product design, customization and visualization with the use of AR was developed. The proposed application was tested in vitro, in a machine shop, in order to gather useful insight into the skills and competencies acquired by the participants during the development of the project.

2.7 On the job training

The purpose of the on-the-job training session is to provide employee with task-specific knowledge and skills in work area. The knowledge and skills presented during on-the-job are directly related to job requirements. Job instruction technique, job rotation, coaching and apprenticeship training are the common forms of on-the job training methods (Alipour M. et al., 2009). Fully on-the-job training theoretically does not involve any off-the-job training. However, it is very rare for 100% of training to take place as part of the productive work of the learner (J. van Zolingen et al., 2000).

On-the-job training impact can be mostly evaluated by surveys. Barzeghar N. (et al., 2011) has conducted one, gathering the main advantages that an organization can acquire from on-the-job training. The most important aspects can be narrowed to the following: a) Improving the quantity and quality of organizations

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output, b) Increasing the chance of organizational success, c) Safeguarding the organizational stability, Decreasing the risk of processes, d) Decreasing organizational costs and expenses, e) Improving the management of the organization, f) Establishing the organization as national and international entities. Most on-the-job training surveys revolve around the following questions:

- How do the employees react towards these courses?
- How does the training course meet the educational, skills and attitude needs of the employees?
- How do the training courses bring about behavioural changes to the organizations?
- How do the training courses, affect the performance of the employees', in their own views and the managers' view?

On-the-job training examples are not widely available among scholar databases, since they are part of an organization's internal knowledge. However, Boeing (Aircraft Company) has been a pioneer in training courses, offering their educational expertise to the public. Some facts from the 2012-2013 Boeing Training Project may provide a better insight on the concept's success. 101 unemployed adults and 39 companies participated in the training project that lasted 10 to 15 weeks S As a result, 91 workers were hired permanently upon completing their training, while also enjoying high salaries (Kobes D., 2013).

The most challenging factor that restricts on-the-job training is cost. Salary for the trainees might be low or even inexistent, whereas the cost of the company is influenced by many factors such as time-consumption, training resources, potential errors due to the trainee's inexperience etc. Therefore, it is important that European and International institutions fund companies for on-the-job training projects, while also encourage and tempt trainees with economic benefits and satisfactory salaries.

3 Initiatives offering education and training for Industry4.0/Industry5.0

3.1 EU Level

3.1.1 EIT Manufacturing

The Education Pillar of EIT Manufacturing (EIT-M) aims at fully contribute to the EIT-M Strategic Agenda and its anticipated impact. Education focuses on humans: engage, connect and empower them to become the backbone of a strong European Manufacturing Innovation Community. Education is key to pursue the strategic objectives of EIT Manufacturing: SO1 Competitive manufacturing skills and social sustainability; SO2 Powerful manufacturing innovation ecosystems; SO3 Globally competitive and resilient manufacturing; SO4 Environmentally sustainable manufacturing; SO5 Manufacturing fit for the digital age; and to contribute to the Strategic Development Goals.[4]

Furthermore, Education contributes to supporting business and innovation along Digitalization, Green transition, increase of Resilience, and other relevant trajectories in Manufacturing.

The Education activities of EIT Manufacturing are structured along three Programs: I) Empower, to develop EIT Labelled journey for students and professionals; II) Connect and Transform to create the infrastructures and the learning experiences that enable individuals and organizations to network, skill, upskill and reskill

[4] EIT Manufacturing 2022, Call for proposals 2023.

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within the Manufacturing Innovation Community; III) Engage to reach out to pupils, youngsters, society at large and other industries to create reciprocal awareness, attraction and involvement to manufacturing.[5]

EIT-M has setup skills.move[6] a dedicated knowledge delivery mechanism based on the concept of MOOC and learning paths and training nuggets. Skills.Move follows a learner-centric approach, therefore all the learning content developed, including digital content (nuggets and learning paths), should be based in clear and sound learning outcomes. Learning outcomes are defined in terms of knowledge, skills, and competences the learner should be reaching at the end of the lesson or course. They enable both learners and trainers to clearly identify what a student is expected to have achieved or have made progress towards at the end of the module (e.g., nugget or learning path). Skills.move manages the training content produced by several education (mainly) and innovation as well as business creation activities of EIT-M. There is learning and training content in several categories of advanced manufacturing including topics such as: Additive Manufacturing, Artificial Intelligence, Augmented Reality, Automated Guided Vehicle – AGV, Big Data, Cloud Computing, Cobots, Digital Twins, Virtual Reality and many more.

In the last two years of operation (2020, 2021) EIT-M has supported twenty-nine (29) education activities. According to the information publicly available the education projects have been analysed and the results presented in "Table 1: EIT Manufacturing education projects". The table provides the following information:

- Project Name: The name of the education activity.
- Description: A short description of the education activity.
- Focus Area: The area that the activity has focused according to the EIT-M classification.
    - Flexible Production Systems for Competitive Manufacturing
    - Low Environmental Footprint Systems & Circular Economy for Green Manufacturing
    - Digital & Collaborative Solutions for Innovative Manufacturing Ecosystems
    - Human-machine Co-working for Socially Sustainable Manufacturing.
    - Platforms for Digitalized Value Networks
    - Additive Manufacturing for full Flexibility
    - Zero Defect Manufacturing for a Circular Economy
    - People and Robots for Sustainable Work
- Knowledge Delivery Mechanisms (KDM): The relevant knowledge delivery mechanism for the project. The KDM the activity has employed to deliver education and training content.

[5] EIT Manufacturing, https://www.eitmanufacturing.eu/what-we-do/, accessed online May 2022
[6] Skills.Move, https://www.skillsmove.eu/, accessed online May 2022

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Table 1: EIT Manufacturing education projects years 2020, 2021

No.	Project	Description	Year	Focus Area	VT[7]		MOOC[8]	G&G[9]	VR/AR[10]	TF[11]	LF[12]	OJT[13]	Comments
1	Discover Manufacturing	Proposes to change the negative perception that many second-level students, as well as their teachers and parents, have of manufacturing by giving them an image of an innovative, imaginative, impactful and society-oriented production activity.	2021	Flexible Production Systems for Competitive Manufacturing	X								Remote VT for training the trainer
2	AM Hospital Learning program	This project aims to empower hospitals to implement Additive Manufacturing (AM) in their facilities and/or make use of a distributed network of local producers of AM parts.	2021	Flexible Production Systems for Competitive Manufacturing	X							X	Remote VT; COVID-19 support
3	Add-Manu	Teaching AM in terms of design-tools, screening suitable AM systems and selecting the right material for the job. Questions of regulatory topics together with international and industrial standards will also be addressed.	2021	Flexible Production Systems for Competitive Manufacturing			X						
4	CAPT'N'SEE	CAPT'N'SEE' (CAPTure aNd foStEr additive manufacturing knowlEdge for luxury industry) is a training program dedicated to professionals who want to enhance their expertise in the use of these technologies.	2021	Flexible Production Systems for Competitive Manufacturing			X						
5	FactoryBricks	The project aims to deliver effective training courses to enable the uptake of industrial Internet of Things (IoT) technologies and smart manufacturing systems. This activity creates an active learning environment for professionals, either executives or technicians, through the delivery of distance training and use of physical, lab-scale models.	2021	Low Environmental Footprint Systems & Circular Economy for Green Manufacturing	X		X						
6	eNHANCE	strENgtHening skills and training expertise in humAN maChinE interaction. This project uses the robotics training platforms and experience of the partners to support executives and professionals with the technical skills and training they need.	2021	Human-machine Co-working for Socially Sustainable Manufacturing	X		X						
7	MNEST II	M-NEST-II aims to deliver innovative courses enabling the financial exploitation of educational assets, such as learning nuggets and Training and Learning Factories.	2021	Human-machine Co-working for Socially Sustainable Manufacturing			X			X	X		

[7] VT: Vocational training
[8] MOOC: Massive Open Online Courses
[9] G&G: Games and Gamification
[10] VR/AR: Virtual and Augmented reality
[11] TF: Teaching Factories
[12] LF: Learning Factories
[13] OJT: On the job training

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No.	Project	Description	Year	Focus Area	VT[7]		MOOC[8]	G&G[9]	VR/AR[10]	TF[11]	LF[12]	OJT[13]	Comments
8	ManuSkills	Manufacturing Skills Observatory and Competencies Framework will develop and implement: 1. a manufacturing competency framework, based on national curricula, the expertise of our industrial partners and recommendations of organizations, such as ESCO, WMF, WEF; 2. mechanisms to observe future skills needs by monitoring different relevant sources, such as the Innovation Hotspot Radar, other Trend Radars of industrial partners, and open job postings, by means of AI and expert evaluation; 3. a diagnostic tool to derive individual competency profiles; 4. a mechanism to analyse training gaps on a macro-level (competency frameworks, curricula) and a micro-level (learning paths, course offerings of the GLP) and integrate the resulting tools into the EIT Manufacturing Guided Learning Platform, Skills.move.	2021	Human-machine Co-working for Socially Sustainable Manufacturing			X						
9	ManuCode	The goal of ManuCode is the development, implementation and evaluation of a connected European summer school for coding in manufacturing. It specifically addresses people who are not already pursuing university study – in particular apprentices and high school students without any prior knowledge, as well as their teachers who are interested in life-long learning	2021	Digital & Collaborative Solutions for Innovative Manufacturing Ecosystems									
10	EMBRYO	Engaging pupils towards technical studies is a very urgent need in Europe and EMBRYO project aims at drastically increasing the amount of pupils interested in manufacturing studies. During the project, an analysis of the current teaching contents will be carried out together with secondary schools and novel manufacturing related contents will be specified for future pupils.	2020	Platforms for Digitalized Value Networks (tentative)	X								Students and pupils.
11	LeaFox	Learning Factory in a Box- [LeaFox] aims to ignite the spark of curiosity for manufacturing in pupils. The image of the dirty and noisy factory has long since served its purpose. The manufacturing sector is highly technological and characterized by constant innovation. It needs young talents who can find their way in a digitalized world, handle it, and continue to innovate.	2020	Additive Manufacturing for full Flexibility (tentative)							X		Students and pupils
12	YML	Young Manufacturing Leaders- [YML] aims to create a network of students and young people who will be mobilized as ambassadors of the manufacturing sector. These young people will spread awareness about the sector's importance and the evolution of manufacturing roles within local communities. The project therefore contributes to the alleviation of job shortages widely felt in the sector.	2020	Zero Defect Manufacturing for a Circular Economy (tentative)									
13	PERFORM	European Periphery Teaching Factory of the Future on Additive Manufacturing- [PERFORM] develop a demonstrator along with technical content, to train students and upskill industry professionals, in both metal AM and relevant cyber physical technologies.	2020	Additive Manufacturing for full Flexibility			X		X	X			

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No.	Project	Description	Year	Focus Area	VT[7]		MOOC[8]	G&G[9]	VR/AR[10]	TF[11]	LF[12]	OJT[13]	Comments
14	MirrorLabs	Creating similar learning environment for students all over Europe for human-robot coproduction – [MirrorLabs]. The aim of this proposal is the development of an common, easy-to-use ICT infrastructure for the existing equipment in the labs of the participating partners. The developed software is planned to be released open source, so that it can be used by other partners within and outside EIT Manufacturing community	2020	People and Robots for Sustainable Work			X		X				
15	FISP	The Field Study Pedagogy (FISP) project aims at designing a Teaching Factory methodology to deploy the training of engineering students on implementing innovation in manufacturing systems, at bachelor and master levels.	2020							X		X	
16	TF KnowNet	Teaching Factory Knowledge Sharing Network- [TF KnowNet] deliver a program where students, researchers and companies work together to mutually develop skills, promote and share expert knowledge through co-creating solutions to industrial manufacturing challenges; extending the established Teaching Factory (TF) paradigm on a network level, while combining it with Open Innovation practices, addressing the demands of both students and professionals.	2020	Additive Manufacturing for full Flexibility	X		X		X	X			
17	LIFT	LIFT European Network of Learning Factories aims at building up the skills of the future and ad-hoc training curricula to ensure competitiveness of European manufacturing SMEs. In addition, LIFT Europe will create a European community to develop, test and disseminate innovative educational methods and tools for the training that will allow sustainable work between people and robots.	2020	People and Robots for Sustainable Work	X		X				X		
18	VR Sustain	Simulation-based training for accident prevention in the automotive industry- [VR Sustain] provides a training environment for students, trainees, and industry workers towards the prevention of accidents in manufacturing processes. Virtual Reality is applied to provide hands-on experience in an off-site environment for simulation-based training	2020	People and Robots for Sustainable Work			X		X				
19	M-Nest-I	Network for Empowering People in Added-Value Manufacturing Systems and Technologies–Phase I aims to establish a robust and sustainable structure to host all types of activities that targets the empowerment of people building the European manufacturing community of the future, from young students to teachers and researchers, from apprentices to technical managers.	2020	People and Robots for Sustainable Work			X			X	X		See M-NEST II
20	AddManu	Additive Manufacturing Teaching Factory- [AddManu] provides hands-on learning nuggets for teaching Additive Manufacturing (AM) in higher academic and industrial education. The targeted course work, which will be made available on the EIT Manufacturing Guided Learning Platform, contains tools for teaching AM in terms of design-tools, screening suitable AM systems and selecting the right material for the job.	2020	Additive Manufacturing for full Flexibility			X						

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No.	Project	Description	Year	Focus Area	VT[7]		MOOC[8]	G&G[9]	VR/AR[10]	TF[11]	LF[12]	OJT[13]	Comments
21	Mach4.0	Learning Factory to Implement Industry 4.0 in Machining- [Mach4.0] is a training and learning activity which demonstrates the practical application of Industry 4.0 in machining processes. The program involves applying data analytics, big data, etc. to new manufacturing trends such as digital twin and zero defects manufacturing.	2020	Platforms for Digitalized Value Networks			X						
22	DIG_WORK	Nuggets on the digital transformation of work on the shop floor- [DIG_WORK] targets three distinct market segments: 1) Master students, especially the ones involved in honoured programs; 2) graduated apprentices involved in specializing master programs; 3) managers and entrepreneurs in medium-sized and large firms.	2020	Platforms for Digitalized Value Networks			X						
23	CPPS 101	The Smart Manufacturing Paradigm – A Tutorial Introduction on Cyber Physical Production Systems – [CPPS 101] makes available for students, young researchers and overall practitioners, didactic materials to educate them regarding the roots, expectations and challenges of the new technologies that are shaping the future of Industrie 4.0 and the smart manufacturing concept. For this, an online course regarding Cyber Physical Production Systems (CPPS) is being created. T	2020	Platforms for Digitalized Value Networks			X						
24	UNICO	Teaching and Learning Nuggets for Interactive Robotics- [UNICO] provides innovative educational content for the EIT Manufacturing's Guided Learning Platform. Already existing, flexible, open-source robotics platforms are used to stimulate creativity and participation inside and outside the classroom setting.	2020	People and Robots for Sustainable Work	X		X						
25	V-Machina	Virtual Machina: Integration of VR-based simulation for the safe interaction and practice of students and workers with machinery and robots- [V-Machina] deals with the familiarization and training of students, workers and practitioners working with industrial machinery and robots via Virtual Reality (VR). V-Machina consists in the creation of a learning environment that allows users to get a direct, immersive experience with selected activities related to the manufacturing sector.	2020	People and Robots for Sustainable Work					X				
26	HiAi	Human in the AI loop – [HiAi] is targeted to shopfloor personnel (e.g., machine operators) and managers (white-collar workers or shopfloor personnel with decision-making competency). Its main goal is to create needed competencies to implement and later collaborate with data-based artificial intelligence (DB-AI) systems.	2020	Low Environmental Footprint Systems & Circular Economy for Green Manufacturing			Z					X	
27	RoboNuggets	Learning Nuggets for Robots and Physical Assistance in Manufacturing – [RoboNuggets] provides state of the art learning content for the Guided Learning Platform (GLP) of EIT Manufacturing. It creates modular, interactive lessons (so-called "learning nuggets") in robotics and physical assistance in manufacturing.	2020	People and Robots for Sustainable Work			X						

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No.	Project	Description	Year	Focus Area	VT[7]		MOOC[8]	G&G[9]	VR/AR[10]	TF[11]	LF[12]	OJT[13]	Comments
28	EMPOWDER	Creating competences for Additive Manufacturing operators for powder material handling- [EMPOWDER] aims to establish comprehensive training for Additive Manufacturing (AM) powder handling, to upskill the AM industry's workforce and add to its value. The online training programs under development in EMPOWDER will aid the progression of the AM industry's production which will have significant social impact by bringing flexibility to customisable mass production lines.	2020	Additive Manufacturing for full Flexibility			X						
29	IDrivE	Industry-Driven Education- [IDrivE] development of a holistic Industry-driven Education Framework, including development of a toolset to support Teaching and Learning Factory Projects, setup of the Guided Learning Platform and integration of the aforementioned tools in a seamless digital ecosystem.	2020				X			X	X		

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3.1.2 Digital Skills and Jobs Platform

The Digital Skills and Jobs Platform[14] is the home of digital skills and jobs in Europe and the heart of the Digital Skills and Jobs Community. It will contribute to the Digital Europe Programme – an ambitious EU programme that strives to make Europe more competitive in the global digital economy through digital capacity-building and ensuring a wide use of digital technologies across the EU. Enforcing the digital skills pillar of the programme, the Platform aspires to boost the digital competencies of European society and workforce. The Digital Skills and Jobs Platform is dedicated to everyone. It provides a wide range of information, resources and opportunities related to the area of digital skills and jobs across all levels, from very basic to advanced. Up-to-date insights are offered in an accessible way to new users, while more experienced professionals can benefit from targeted content relevant to their field of expertise. Additionally, a collaborative space is available for Community members to network, interact and grow together. The platform acts mainly as mediator offering matchmaking services for different national, European and Interanational training material providers.

3.1.3 European Digital Innovation Hubs

European Digital Innovation Hubs (EDIHs)[15] will play a central role in the Digital Europe Programme to stimulate the broad uptake of Artificial Intelligence, High Performance Computing (HPC) and Cybersecurity as well as other digital technologies by industry (in particular SMEs and midcaps) and public sector organisations in Europe. EDIHs are onestop shops that help companies become more competitive with regard to their business/production processes, products or services using digital technologies, by providing access to technical expertise and experimentation, so that companies can "test before invest". They also provide innovation services, such as financing advice, *training and skills development* that are needed for a successful digital transformation.

EDIH offer skills and training services in the area of advanced digital skills (e.g. by coordinating with education providers for the provision of short-term training for workers and internships for students)". To ensure the appropriate level of digital skills within the supported organisations in order to make the most of digital innovations technologies, EDIHs' services include advertising, hosting or providing of training, boot-camps, traineeships, as well as supporting the implementation of the shortterm advanced digital skills training courses and job placements developed as part of the Digital Europe Program Advanced Digital Skills pillar.

3.2 National level

In this chapter education initiatives in Industry4.0 topics in EU level are presented. The list is not complete as several EU countries are not included. The selection of countries has been driven by the countries' representation in CF II project. However, the examples provided here are indicative of the activities taken place in national level in EU and UK.

3.2.1 Austria

3.2.1.1 Introduction

In 2013 "Industry 4.0" was officially presented during the Hannover Fair. In 2014 first initiatives started in Austria. Among these were activities to find a national Platform, that was officially opened in 2015. During these first years there was a strong focus on understanding the concept of Industry 4.0. Many of the technologies that are summarized under Industry 4.0 were apparently on the curricula of Universities and

[14]Digital Skills and Jobs Platform https://digital-skills-jobs.europa.eu/ accessed online May 2022
[15] EDIHs, https://digital-strategy.ec.europa.eu/en/activities/edihs, accessed online May 2022.

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Applied Universities and other educational institutions. Therefore, the shift to a more Industry 4.0-related focus was performed in a remarkably short time. Currently many of the educational institutions have a focus on Industry 4.0. These include universities and applied universities, vocational training schemes, adult education and lifelong learning. In all nine Austrian federal states there are tertiary training institutions focussing on aspects of Industry 4.0 (Fig. 2).

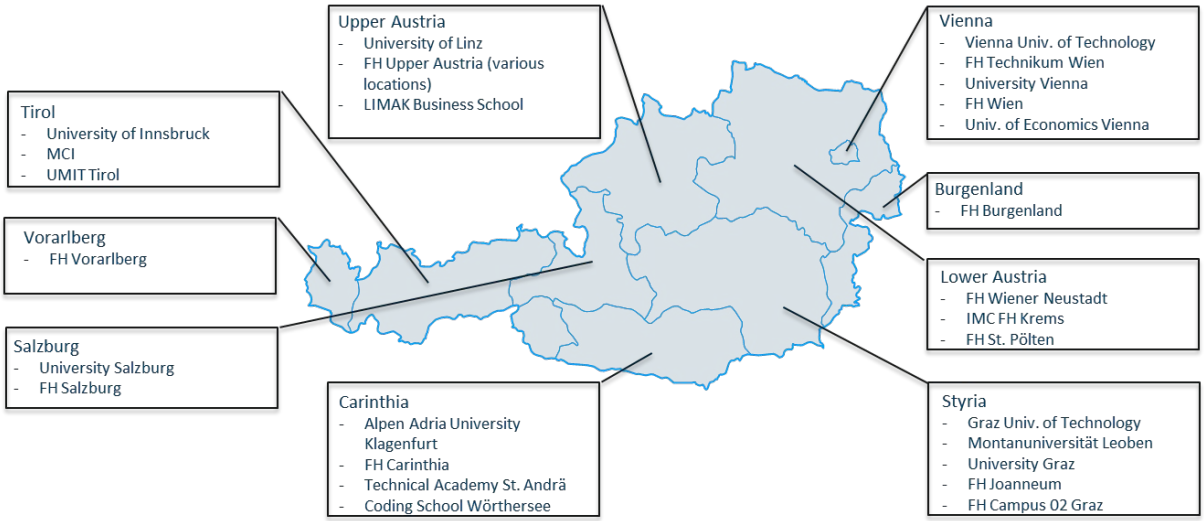

Figure 2: Overview of tertiary training institutions in Austria

3.2.1.2 Pilot Factories

There were some pioneering activities that funnelled the development of training in this field. The most important one was a public funding for setting up Pilot Factories by the Federal Ministry for Climate. The first one was established in Vienna – Aspern by the University of Technology Vienna as a pilot project in 2015. A call for further pilot factories was issued in 2016 which led to the establishment of two further pilot factories; one is the Smart Factory @ TU Graz and the other one the Linz Institute of Technology Factory (LIT Factory).

Further pilot factories were built at various Applied Universities. Among these are the Smart Production Lab at the Applied University Joanneum in Kapfenberg, the Centre for Smart Manufacturing at the University of Applied Science Upper Austria in Wels, the Robotics Lab at the FH Technikum Wien, the Digital Factory Vorarlberg in Dornbirn, the Learning Factory at the University of Applied Sciences Kufstein, and others. Furthermore, there was infrastructure established in Vienna, Graz and Kapfenberg that focuses on security (Fig. 3).

These pilot factories play an important role as training activities, crystallized around these pilot factories, not only for students, but also for businesses including SMEs and many projects aiming at providing education and training use on the infrastructure of these pilot factories.

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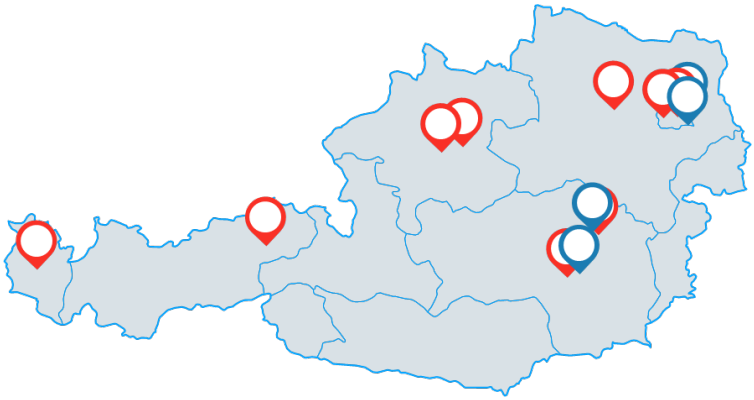

Figure 3 Overview of pilot factories for Smart Production (in red) and for Security (in blue)

3.2.1.3 Digital Innovation Hubs (DIHs)

Digital Innovation Hubs (DIHs) provide digitisation support and training to SMEs. There are 6 national DIHs in Austria; three were selected in 2019 and three in 2021, following calls for proposals (Fig. 4).

The first three DIHs selected are

- the Digital Makers Hub, focussing on co-ideation, co creation and digital culture
- the DIH East, focussing on 3D-printing, blockchain, IT security, IoT, sensors and connectivity and
- the DIH West focussing on digital transformation and innovation, Industry 4.0, eServices, AI and security.

From the second call for proposal, the following three DIHs were selected:

- innov:ATE, focussing on robotics, automation, AI, smart industry & infrastructure, big data, forecasts and simulation with a focus agriculture, forestry and the energy industry
- DIH South, focussing on production technologies, digital business models and processes, data science and logistics; they have also established a cross-cutting topic, human resources and the new generation
- DIH Work, focussing on the digital transformation and innovation, Industry 4.0, eServices, AI and security

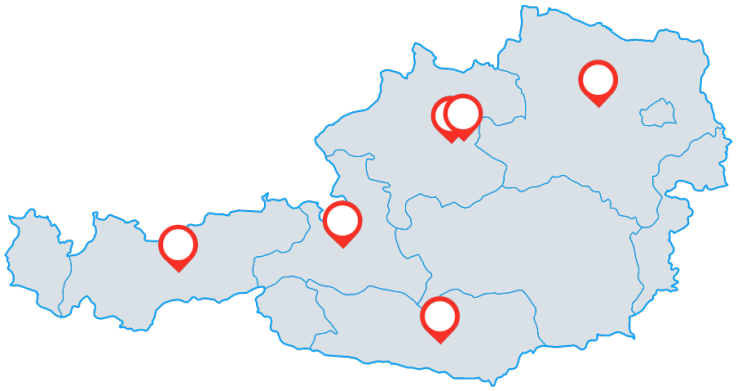

Figure 4 National Digital Innovation Hubs in Austria

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3.2.2 Finland

3.2.2.1 Finnish initiatives in the RD&I sector

Finland is ranked high in digital skills and Europe's leading countries for 5G, 6G, AI, and sustainable digitalisation. While building on these strengths, Finland has the ambition to be a forerunner in the digital transformation of manufacturing, production and processing industries. In particular, the national Artificial Intelligence 4.0 programme aims to make Finland one of the winners of the twin transition by 2030 by increasing industrial digitalization while simultaneously responding to the challenges posed by green transition. The program highlights the importance of collaboration: digitalisation should be done in cooperation between companies, research and academia as well as training institutes and public organisations. The program proposes actions to develop digital skills in small and medium sized industrial companies as well as measures to strengthen top competence and research in e.g., artificial intelligence, robotics, quantum technologies and connectivity.

In line with this, even the concept of Industry 6.0 has been introduced as "Ubiquitous, customer-driven, virtualized, antifragile manufacturing"[16]. The Industry 6 concept emphasizes shared RDI environments that have a great potential to combine the best features of platform economy with smart (regional) specialization. Industry 6.0 highlights the need to raise the level of ICT-knowledge across industry. Among other recommendations, it proposes the creation of the Virtual Industry 6.0 University and a test factory network serving as an open testbed for the Finnish platforms.

3.2.2.2 Innovation along with education

The collaborative approach and close linkages between the universities, research organisations and industry are one the core elements of the Finnish innovation environment and there are several initiatives building on this. For instance, Reboot IoT Factory[17] project has brought together forerunner companies, research organisations and digital solutions providers that have created innovative solutions to revolutionize the competitiveness of the Finnish manufacturing industry. Reboot IoT Factory has resulted in more than 100 proof of concepts solving digitalisation challenges both on factory floor and in the value network. The concept has enabled fast competence sharing and effective collaborative innovation capacity and scale-up of solutions. Similarly, Sustainable Manufacturing Ecosystem[18] project supports Green, Circular Economy oriented, and Sustainable Digital Transformation of Finnish Manufacturing SMEs. It links existing ecosystems and pilot lines, integrate digital platforms and DIHs, and enrich previous results in the domain of Industry 4.0. The project's goal is to determine what skills and competencies would be in demand in the next 5 to 10 years in Finnish manufacturing sector, and to design courses for life-long learners to support workforce. The project results in pilot courses (e.g., Robot offline programming, Sustainability reporting, and Fundamentals of Machine Vision) that are based on existing educational offerings and infrastructures. However, the challenge is the project form of these initiatives, i.e. the shared research and development work takes time to gain the full speed and often the project funding ends when the process is strongly ongoing. Therefore, the companies may have difficulties to find the training and education services that are in line with their needs.

In order to solve the challenge of project-based development, the Sustainable Industry X[19] initiative SIX targets to an inclusive, long-term and ambitious entity. The aim is to form a unifying renewal vision and agenda for Finland together with the industry, research, and public sector. SIX helps actors to form industry-

[16] Industry-X-White-Paper-3.5.2021_Final.pdf (alliedict.fi)
[17] Reboot Iot Factory - Reboot Iot Factory
[18] Sustainable Industry Ecosystem | Collaboration Framework for Green and Digital Technologies | Tampere Universities (tuni.fi)
[19] SIX | Sustainable Industry X

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driven clusters, such as SIX Mobile Machines or SIX Manufacturing, that promote common agenda setting, innovation and competence development around different topics. SIX has also submitted an application for Digital Europe program EDIH call. The SIX EDIH focuses on advanced manufacturing technologies, e.g., enabling economically feasible manufacturing of lot-size-one and small batches, data sharing and enabling cyber security capabilities, as well as AI and analytics, enabling value from data. SIX EDIH has ambitious targets for up-skilling and re-skilling and for knowledge and technology transfer. The SIX EDIH educational partners (e.g. technical universities and universities for applied sciences) have worked extensively in several projects for the development of higher education, such as A new Ecosystem for Learning and FiTECH 5G (expert training in 5G technology including IoT, embedded internet, system vulnerabilities, and wireless technologies). The pedagogical solutions and collaboration models directly support skills and training needs faced by the manufacturing companies.

3.2.3 France

Profound changes in skills and qualifications arise with the industrial metamorphosis brought about by digital and new technologies. People, placed at the heart of the Industry of the Future, constitute an important key to success in the transition of companies towards the industry of the future.

"Osons l'industrie" is a collaborative project coordinated by the **Alliance Industrie du Futur (AIF).** With the aim of providing information on the development of professions, qualifications and skills to young people in a situation of orientation and to employees in activity or in professional retraining, the portal "Osons l'industrie" is also a source of content for initial and continuing training players.

Professions are categorized in 5 families: maintenance, big data, management, production and supply chain. Each identified individual profession is described in a dedicated sheet including the main missions, the skills to acquire, a typical working day, illustration videos, and **the related French training offer**. Several organisations and initiatives stand out relating to the French education and training offer for Industry 4.0/ Industry 5.0. They are illustrated by, but not limited to, the following examples.

3.2.3.1 ENSAM

ENSAM (Arts et Métiers) is committed to solving industrial challenges and societal issues, which are constantly changing. One of their main activities is training engineers specializing in sustainable technologies: engineers capable of designing products and systems that respect the environment, but also of controlling an industrial organization by controlling risks and costs.

These skills are those expected by recruiters today. With eight campuses and three institutes spread across France, Arts et Métiers enjoys exceptional proximity to the industrial environment. This unique positioning makes it possible to align, as close as possible to the field, the content of the programs and the needs of the companies. An ambition supported by international openness: the network of 170 foreign partner schools and universities allows a wide variety of study paths abroad.

A major engineering school, Arts et Métiers is constantly enriching its **initial and continuing training offer**. It now offers general engineering and specialist engineering courses (work-study), a technology bachelor's program, as well as 27 research masters, 16 specialized masters ® & 1 MBA and doctoral studies. The entire spectrum of technological training in higher education is thus covered to meet all needs and expectations.

Industry of the Future training include for instance:

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- Digital engineering (of products and systems) for the Industry of the future : understanding and implementing modern engineering processes for complex products and systems (looking at production systems, services and associated supply chains).
- Digital model and virtual immersion: technologies for digital models, 3D interfaces and their use in virtual immersion in all fields of application: health, industry, building.
- Energy efficiency for the factory of the future
- Factory of the Future 4.0: from 3D Prototyp@ge to UGV (PROTeUS) techniques for machining difficult materials and complex surfaces, part of the projects and training on a **technical platform** with means of manufacture and experimentation, **industrial testimonials given by industrial speakers** (30% of the training).
- Industry 4.0 Management: 1 year to educate and equip future engineers to enable them to make decisions adapted to the complex and dynamic context of the factory of the future (industry 4.0).
- The "Mechanical, Smart Manufacturing" Specialty trains field engineers on technologies and new approaches to the Industry of the Future such as Smart Manufacturing.
- The Specialized Master® ColRobot : training robotic experts based on enhanced skills in innovative robotics and more particularly in collaborative robotics, **based on the Agile Factory technological platform** equipped with innovative industrial means (industrial robots with serial and parallel structure, collaborative robots, industrial holonomic mobile base, advanced measurement means such as laser tracker…).

Arts et Métiers is also a founding member of the **FactoryLab** community which responds to problems shared by manufacturers and illustrated by use cases around the following three axes:

- ➢ the flexible digital factory: interoperability and modeling / simulation / optimization of the production tool,
- ➢ manufacturing automation and control,
- ➢ physical and cognitive assistance to operators.

In this context, Arts et Métiers offers a range of Industry 4.0 training courses **for manufacturers** with the aim of providing them with the keys to decide how and when to integrate new technologies into their companies.

3.2.3.2 IMT Institut Mines Telecom

IMT Institut Mines Telecom, as part of the Osons l'Industrie du Futur project, questions the impact of digital transformations on industry professions in order to anticipate and support the new needs of companies in terms of skills and qualifications. IMT develops initial and continuing training offers for Industry 4.0, such as:

- ✓ Intended **for high-school students**, the 10 hour MOOC "Dare the professions of the industry of the future" introduces the sectors and the diversity of the professions of the industry of tomorrow.
- ✓ Bachelor of Technology – Managing the digital transition in industry
- ✓ Bootcamp IMT Disrupt Campus entitled "Digital transformation at the service of the company and the industry of the future" is a 40-hour online training in the form of **SPOC (Small Private Online Course)** and a collective introductory conference.

3.2.3.3 CampusFab

CampusFab is a 2000 m² factory of the future designed as a shared tool, complementary to the existing training offer and meeting "clean factory" environmental requirements. In its modernity, it positions digital continuity at the heart of industrial spaces.

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A digital industrial operations management system connects 5 dedicated spaces:

- Machining center
- Additive manufacturing center
- Assembly / assembly department
- Maintenance and means of production division
- Digital room: control, analysis of data and processes

The training offer at CampusFab aims to allow an effective integration of the methods of the industry of the future in companies.

3.2.3.4 The CMQE Industrie du Futur, a territorial offer

The CMQE Industrie du Futur is made up of members committed to strengthening the industrial sector in the mechanical sector "Territory of Industry" of region Aurillac-Figeac-Rodez. This territory is identified and labeled by the French State, as part of its "Transforming our industry through digital" plan, as having strong industrial challenges. The Campus des Métiers et des Qualifications Industrie du Futur is a label awarded to a network of secondary, general, technological, vocational and higher education establishments, providing initial or continuing training, training bodies, research laboratories and economic and associative partners, focused on the mechanical industry. It federates this network of partners, to support the sector, through training and innovation, through the economic and social development of the territory.

3.2.3.5 CETIM Academy

CETIM is the French mechanical expertise center. CETIM Academy offers specific training for Industry 4.0, with courses in the following fields:

- Transformation support. Understand the industry of the future and experience it. Through experimentation during a serious game, get in condition to deploy 4.0 concepts in order to accelerate digital transformation in the service of the performance of your company's operations.
- Energetic efficiency
- Operational excellence, Lean management
- Digital transformation
- Technological transformation
- Ecodesign

3.2.4 Germany

The solution for more jobs and good work through Industry 4.0 according to Experts from acatech - German Academy of Science and Engineering[20] lies in the qualification and further training of people and the creation of building offers around digitalization issues. Although most of the companies surveyed see Industry 4.0 as an opportunity, they have hardly established it in their operations to date. That is why German initiators are working together with experts from politics, business and research to develop training programs for Industrie 4.0.

[20] https://www.acatech.de/allgemein/schluessel-zur-industrie-4-0-mittelstand-braucht-mehr-weiterbildung/

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 873086.

Several providers in this context with the Industry 4.0 related initiatives offering education and trainings could be highlighted as follows:

Provider: Federal Ministry for Economic Affairs and Climate Action
Offeing: Mittelstand-Digital
Source: https://www.mittelstand-digital.de/MD/Redaktion/DE/Artikel/Mittelstand-4-0/mittelstand-40-kompetenzzentren.html

The Federal Ministry for Economic Affairs and Climate Action supports small and medium-sized enterprises in digitization with regional and thematic centers of Mittelstand-Digital. The network offers competent and provider-neutral contact points throughout Germany for information, sensitization and qualification. Here, small and medium-sized enterprises can experience the benefits of digitization for Industry 4.0 through practical examples, demonstrators, information events and mutual exchange. They receive comprehensible, neutral, practice-oriented information as well as concrete help in designing and implementing a digitization strategy. The educational offerings range from workshops, training courses, practical tests, webinars or consultation hours.

Provider: **IHK Akademie Schwaben**
Offeing: IHK Akademie Schwaben
Source: https://www.ihk-akademie-schwaben.de/

Since the founding of the Swabia Education Center in 1971, the Swabia Chamber of Commerce and Industry (IHK Akademie Schwaben) has become the number one provider of skilled labor in southern Germany. All efforts pursue one major, overriding goal: securing skilled workers, and doing so as practically as possible. The continuing education programs also keep pace with developments in the economy, especially in the area of Industry 4.0. The IHK Academy offers online training, such as online seminars, as well as classroom events and blended learning programs. Here, online learning phases are didactically interlocked with classroom events, thus combining the advantages of both learning arrangements.

Provider: **Verband der Elektrotechnik Elektronik Informationstechnik e.V**.
Offeing: VDI Wissensforum
Source: https://www.vdi-wissensforum.de/industrie-40-weiterbildung/

Participants can benefit from the wide range of Industrie 4.0 courses on offer at the VDE Wissensforum, for example on automation technologies, trends in robotics or intelligent communication systems, and find out about the latest developments. In seminars, conferences and congresses, participants can acquire extensive basic and in-depth knowledge on Industrie 4.0, taught by experienced experts. The offering is aimed at a broad audience, from career changers to experienced specialists. Other offerings also include Industrie 4.0-related topics such as automation, IT security and process industry.

Provider: **Plattform Industrie 4.0**
Offeing: Industrie 4.0@Mittelstand and the Research Council
Source: https://www.plattform-i40.de/IP/Redaktion/DE/Standardartikel/ihk-roadshow.html

Since the beginning of 2016, the German Industry 4.0 Platform has been working with regional chambers of industry and commerce (IHKs) to support small and medium-sized enterprises (SMEs) on the topic of Industry 4.0 as part of the "Industrie 4.0 @Mittelstand" series of events. The activity has a specific goal, namely to raise awareness of the opportunities that the fourth industrial revolution opens up for small and medium-sized enterprises and to provide a place to exchange ideas with experts on the topic of Industry

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4.0. The research questions are supported by the advisory board, which advises the Industrie 4.0 platform and accompanies the implementation and further development of the research recommendations by industry. To support companies, the activity therefore provides participants with information, concrete guides and results from the platform's working groups and explains Industrie 4.0 topics to companies in a practical way and provides essential guidance on standards. Participation in the events is open and free of charge. One of the success factors of the activity is the close cooperation with partner companies on site, which contribute their own experience.

Provider: **Festo Didactic GmbH & Co. KG**
Offeing: Festo Didactic
Source: http://www.festo-didactic.com/de-de/
Festo Didactic is one of the leading German educational service providers in technical education and training. The product and service portfolio offers customers holistic educational solutions in all technology areas of industrial automation, such as pneumatics, hydraulics, electronics, electrical engineering, mechatronics, CNC, energy efficiency and mobility, renewable energies, industrial maintenance, telecommunications and others. In the context of Industry 4.0, Festo Didactic offers a holistic approach and a specialized qualification program. Thus, Festo Didactic also implements learning environments / laboratories, learning factories, e-learning solutions and training programs that appropriately complement learning centers and, thus, can systematically prepare people to work in dynamic and complex industrial environments. In train-the-trainer courses, Festo Didactic supports and prepares teachers and offers seminar concepts on various workplace-relevant topics related to Industry 4.0. Knowledge building succeeds through lifelong learning and exchange with others via the Industrie 4.0 Online Community, where participants can continuously expand their knowledge by sharing ideas and experiences on Industrie 4.0. Industry 4.0

Provider: **Bosch Rexroth AG, Drive & Control Academy**
Offeing: Bosch Rexroth Academy
Source: http://www.boschrexroth.de/training
The Bosch Rexroth Academy offers a wide range of training courses, from the basics of Industry 4.0 to advanced and special courses. Interested parties can book standard training courses or put together an individual training course tailored to their company-specific needs. The offering includes online face-to-face training, eLearning, online training and blended learning. The methods can be combined, for example online training for the theory part followed by hands-on classroom training. The courses cover a wide range of topics such as industrial hydraulics, mobile electronics, connected industry, electric drives and controls, linear and assembly technology and others.

Provider: bbw – Bildungswerk der Bayerischen Wirtschaft gGmbH
Offeing: The bbw Group
Source: http://www.bbw.de
The bbw is a company of the bbw Group, which has been developing concepts for and with the business community for more than forty years and is one of the leading institutions for vocational training and qualification. All seminars, courses and events are conducted exclusively by recognized experts and experienced practitioners with many years of company and industry knowledge. Qualifications on various Industry 4.0 topics are offered e.g. in the Technology Center 4.0. The innovative "Digital Learning Factory"

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format enables training participants to experience specialist theoretical and practical learning in a fully automated production environment. The model facilities of the Digital Learning Factory are located on premises in Munich and Nuremberg. The center thus offers the opportunity to demonstrate current developments such as robotics, sensor technology, automation technology and additive manufacturing processes (3D printing) and to conduct the training courses.

Provider: **Industrie- und Handelskammer für München und Oberbayern**
Offeing: Industrie- und Handelskammer für München und Oberbayern
Source: https://www.muenchen.ihk.de; https://www.ihk-muenchen.de/industrie/
Industry 4.0 and the digitalization of the economy is one of the top future topics for Upper Bavaria as an industrial location. The Chamber of Industry and Commerce for Munich and Upper Bavaria regularly holds events on specific aspects of Industry 4.0 such as Big Data, business models, artificial intelligence (AI), logistics, IT security and law, and changes in the world of work. Particular emphasis is placed on practical examples that can serve as inspiration and role models for other companies.

3.2.5 Greece

With the support of the General Secretariat for Research and Innovation in Greece the Teaching Factory Competence Center (http://teachingfactory-cc.eu/) has been setup in Patras, Greece under the coordination of LMS. The Teaching Factory Competence Center (TF-CC) is oriented on providing education, innovation, and entrepreneurial services to the manufacturing industry. It focuses on enabling the knowledge exchange between the academia and industry and on creating added value for the services and products of manufacturing companies by promoting innovative technology and research activities. Additionally, TF CC is involved in Business Creation activities by offering and supporting Entrepreneurial Training actions. From this scope, the TF CC provides a set of Learning Services and Innovative Technical Services to their customers aiming to the Interdisciplinary learning, research & experimentation and to exploit of research results towards industrial applicability in pilots. TF CC is strongly connected with EIT Manufacturing group by offering interconnection services with it through EIT Manufacturing RIS Hub operating in Greece as well as Education and Training services. Its Technological Areas have emerged from the needs and challenges of the national manufacturing industry, combined with a set of solutions based on the technologies of the 4th Industrial Revolution. The Teaching Factory paradigm integrates research, education, innovation aspects, creating a Knowledge Triangle essential for boosting National and European competitiveness both in research and entrepreneurship. TF CC will bring together industrial and academic actors and facilitate the launch of collaborative manufacturing training projects with mutual business interest for both types of actors.

3.2.6 Ireland

3.2.6.1 IMR Training Courses

Irish Manufacturing Research (IMR) engages in the culture of learning by doing. Our pilot factory in Mullingar is a workshop for helping demystify, de-risk and deliver emerging technologies for business results, very much in the ethos of I4.0. IMR builds learning programs to continuing professional development standards, Continuing Professional Development (CPD), and strives for lasting impact with signature courses like Innovation through Robotics that emphasizes the necessary digital blend for learning with the richness of human instructor interaction. Through practical, accredited learning courses IIoT, Machine Learning & Data Science offers participants thought leadership in a virtual world, with critical thinking in the real world, delivering analytical rigor and an appetite for new knowledge to enable industry employees succeed at the

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cutting edge of advanced manufacturing. IMR hosts monthly webinars in relation to topics around I4.0 (12 webinars in 2021 with over 420 attendees and 2000 Youtube views to date). In parallel, Table 2 presents a current I4.0 related training course run by IMR and attended by over 220 participants since inception (Q3 2021).

Table 2: IMR Training Course currently on offer

Course name	Short Description	Duration	Attendance to date
Mills CNC Training	Irish Manufacturing Research has teamed up with the prestigious Mill Training Academy to make their high-quality, professionally-delivered and competitively-priced CNC Programmer and Operator training courses available to Industry in Ireland.	3 days	6
Innovation through Robotics	Throughout this signature course you will be supported by IMRs expert instructors in putting together an innovation approach, specific to your business. The course is intended for anyone planning their automation strategy and interested in understanding and using Robots; it covers the core concepts plus state-of-the-art approaches, planning and evaluating robotics, plus outlining the pitfalls involved.	4 weeks (37hrs CPD)	76
Introduction to Industrial Internet of Things	In this course, Mike Hibbett – a veteran of IIoT hardware design provides a broad, un-biased introductory overview of Industrial Internet of Things, the hype, acronyms, pitfalls and challenges. It is for manufacturing process engineers and project managers who will learn about how sensors communicate, the role of security 'sensing' and types of suitable/problematic environments, as well as understanding and potentially employing IIoT technologies.	1 day (7hrs CPD)	55
Introduction to Machine Learning and Artificial Intelligence for Manufacturing	In this course Dr Brian O'Halloran – a highly experienced data scientist – provides a broad and unbiased overview of the machine learning landscape, for anyone interested in understanding & potentially using machine learning from the introductory building blocks to more state-of-the-art approaches, with an overall lean towards uses in the manufacturing domain. It covers core machine learning concepts plus state-of-the-art approaches.	1 day (5.5hrs CPD)	27
Introduction into UX in Manufacturing	This course is designed to introduce participants to User Experience (UX) research and design, in general and specifically to manufacturing. The fundamentals of Design Thinking are also covered. All learnings will be applied in a practical workshop, wherein solutions to UX challenges in manufacturing will be explored.	1 Day	9
An Introduction to Conformal Cooling	This exciting new training programme with Irish Manufacturing Research partnering will give you a deeper understanding of Conformal Cooling, it's industrial and customer considerations together with a deeper understanding of methods of manufacture with a focus on Additive Manufacturing. By the end of the training, you will not only be able to gauge its potential benefits for your own organisation but, gain a far broader understanding of its core concepts and current industrial practices and limitations.	4 days including workshop	15

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Certification, Qualification, Standardisation in Additive Manufacturing	As Additive Manufacturing (AM) moves from the production of prototypes to the manufacture of end-use parts, certification, qualification, and standards (CQS) become vitally important. These are important, not just in highly regulated industries or safety critical applications but wherever the AM component can adversely affect the performance of the product. This professional training course will extend attendee understanding in the steps which must be followed to enable the safe and effective adoption of Additive Manufacturing (AM) for end-use parts and the impact on the way the business operates, from the shop floor to the boardroom.	3 Days	33
Total			**221**

In addition to our training offering listed in Table 2, IMR is also strategic partners with the Manufacturing Technology Centre (MTC) in the UK. This partnership adds real value to I4.0 areas of research and development and aims to increase research, technology and skills transfer between the UK and Ireland. By sharing resources, IMR grants a position that enables its networks to access even more extensive training portfolio, supporting business improvements both now and in the future.

3.2.6.2 IMR and the Smart Industry Readiness Index (SIRI)

The Smart Industry Readiness Index (SIRI) was created by the Singapore Economic Development Board (EDB) in partnership with a network of leading technology companies, consultancy firms, and industry and academic experts. It is supported by the World Economic Forum (WEF) as a global initiative to help companies decide how and where to apply Industry 4.0 to maximise benefits. SIRI comprises of a suite of frameworks and tools to help manufacturers regardless of size and industry to start, scale, and sustain their manufacturing transformation journeys.

IMR has the first 3 Certified SIRI Assessors (CSA) in Ireland (Accomplished Q3 2021) as part of the Irish Government National strategy on Digitisation and Industry 4.0. CSAs have the requisite knowledge and skills, beyond a simplistic understanding of the SIRI framework and tools, to credibly conduct an Official SIRI Assessment. To date IMR have delivered 11 workshops (2 days) specifically around I4.0 and the challenges faced.

3.2.6.3 Industry 4.0 / 5.0 Training Across Ireland.

An Industry 4.0 Strategy is a key output of Future Jobs Ireland, the Irish Government's new economic pathway to ensure that Ireland is well placed to prosper in a rapidly changing global economy[21]. The education and training system across Ireland has begun to respond to the challenges of Industry 4.0 and existing programmes are being leveraged to deliver the skills required at all levels.

For Corporate Management Level programmes such as

- Enterprise Ireland's Management Development Programme,
- Innovation for Growth
- Tailored Management Company Support

[21] *https://enterprise.gov.ie/en/Publications/Publication-files/Irelands-Industry-4-Strategy-2020-2025.pdf*

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- LEOs Management Training Programme

are accessible to all indigenous and foreign-owned firms within Ireland. These are delivered by Skillnet Ireland and via the Springboard+ programme. These programmes provide firms with the opportunity to develop the strategic leadership and management skills required to deliver on Industry 4.0 implementation strategies. To further support individual firms to develop and implement training plans that meet their specific needs, the 'Regional Skills Fora'[22], established by Department of Education and Skills (DES), acts as a single contact point with employers in each region within Ireland, allowing them to connect with the range of services and supports available across the education and training system. Work is already ongoing through the 'Regional Skills Fora' and the "Skills for Growth Initiative" to give employers the necessary tools to identify their skills needs, including those related to Industry 4.0. Once skills needs are identified, the Regional Skills Fora will facilitate engagement between enterprise and the Education and Training System to respond to these needs.

At a postgraduate level, Science Foundation Ireland offer an Industry Fellowship programme that support employees to spend time in academic environments participating in collaborative RD&I, receiving training and developing new skills in Industry 4.0. In addition, the Irish Research Council Enterprise Partnership Scheme supports the placement of postgraduate or postdoctoral researchers into firms to work on Industry 4.0 activities

Moreover, the Industry 4.0 focused Science Foundation Ireland research centres (I-form and Confirm), have targets set for the number of PhD Masters graduates to be directly supported by the centres. These graduates and postdoctoral researchers will be highly skilled in technical areas under the Industry 4.0 umbrella and will be key to producing a pipeline of specialist skills in Industry 4.0 for enterprise.

Industry 4.0 Skillnet (https://industry4skillnet.com) is co-funded by Skillnet Ireland and network companies. Skillnet Ireland is funded from the National Training Fund through the Department of Further and Higher Education, Research, Innovation and Science. They currently have a suite of Industry 4.0 Training offerings in the Manufacturing space (Including AI for Business Strategy Workshop and Industry 4.0 Technologies)

Engineers Ireland (https://www.engineersireland.ie/Professionals) is the voice of the engineering profession in Ireland. With over 25,000 members, Engineers Ireland make up a community of creative professionals delivering solutions for society. Course run by Engineers Ireland include "Introduction to Industry 4.0 Smart Factory & CPS I4.0 in Ireland". A range of industry experts, academic researchers, and featured guest speakers discuss the benefits and challenges of implementing various industry 4.0 technologies in industry to Industry.

3.2.7 Italy

In Italy the most important players that provide education and training for Industry 4.0 and Industry 5.0 can be classified into three main categories: Competence Centers, Higher Technical Institutes, and Universities. In addition, lots of private education and training providers offer different learning opportunities to companies and workers that want to develop their competencies. Since it is not possible to report the whole Industry 4.0-related offer available in Italy, a brief description and some relevant examples of each of the above-mentioned categories are provided in the following paragraphs.

3.2.7.1 Competence Centers

Competence centers of the Industry 4.0 National Plan are public-private partnerships whose task is to carry out orientation and training activities for companies on Industry 4.0 issues as well as support in the

[22] *https://www.regionalskills.ie*

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implementation of innovation, industrial research and experimental development projects aimed at the realization of new products, processes or services (or their improvement) through advanced technologies in the industry 4.0 field. There are 8 Competence Centers:

- **MADE**[23]: MADE's Digital and Sustainable Factory supports the enterprises in their digital transformation path towards Industry 4.0. It is part of the industry 4.0 Italian ecosystem created by the Competence Centers and the Digital Innovation Hubs. MADE provides a wide range of knowledge, methodologies, and digital tools that encompass the entire product lifecycle: from the design to the engineering, from the production management to the delivery to the customer, and the end of the product life cycle. Manufacturing 4.0, Product 4.0, Process 4.0, Logistics 4.0, Maintenance 4.0, Data 4.0, Responsible manufacturing, the green factory, Industry 4.0 and society, and Cyber Security are among the educational topics discussed in this center. which are covered in the form of strategic course, Experiences, Technical – operational courses, and Training courses.

  The School of Skills 4.0 is organized in single courses, experiences and training courses. The single courses have variable duration from 4 to 32 hours and can be attended individually or within a longer duration path or experience. They are distinguished between strategic, lasting from 4 to 16 hours and offering a complete overview of the chosen topic, and technical-operational ones lasting 24 or 32 hours, more practical and experiential. The participant can select from a range of 5-day experiences, complete 15-day courses or choose just some of the individual courses. For each module, experience or path it is possible to build an ad hoc offer of duration and content customized according to needs. At the end of the training experience, a MADE - Industry 4.0 Competence Center "Expert" certificate will be issued based on the number and level of courses attended.

- **CIM4.0**[24]**:** Competence Industry Manufacturing 4.0 aims to make a decisive contribution, at the local and national level, to the acceleration of the transformation process in a significant portion of the Italian production system, with particular attention to SMEs, proposing itself as an integrated hub of reference for what concerns the diffusion of skills and best practices, also with training actions and experience in the field, in technological sectors and industrial fields typical of the Piedmontese territory, but also widespread in other Italian regions. CIM4.0 is based on the concept of “pilot lines”, or manufacturing demonstration lines.

  The general scope of the educational activities of this center is related to industrial subjects such as Additive manufacturing, Data Science, Cyber Security, Digital transformation, and protective maintenance, which are taught at the introductory and advanced levels.

- **BI-REX**[25] (Big data Innovation-Research Excellence): BI-REX is one of the eight national Competence Centers set up by the Ministry of Economic Development as part of the industry 4.0 government plan, with a specialized focus on Big Data. Big data & Internet of things (IoT), Additive Manufacturing, Robotics, and Finishing & Metrology are the main subjects that are covered by this competence center.

- **ARTES 4.0**[26] (Advanced Robotics and enabling digital Technologies & Systems 4.0): ARTES 4.0 was created to unite University Partners, Research Bodies, Highly Qualified Training Institutes, Foundations, Third Sector & No Profit entities, but also private Associations and Innovative Companies in order to provide

[23] https://www.made-cc.eu/scuola-di-competenze-40?lang=en
[24] https://cim40.com/
[25] https://bi-rex.it/
[26] https://www.artes4.it/en/web/guest/home

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Partners and industry (in particular SMEs) technologies and services responding to their needs through guidance, training, innovation projects, industrial research, and experimental development

Big data & Analytics, Cloud computing, Industrial Cyber Security, Artificial Intelligence, Additive & advanced manufacturing, robotics, and Simulation are among the main topics covered by this center.

- **SMACT competence center**[27]: SMACT is one of the 8 highly specialized Industry 4.0 Competence Centers born in Italy on the initiative of the Ministry of Economic Development. It is a public-private body that systematizes the skills in the 4.0 field of Research, technology providers, and early adopter companies. SMACT was born in Trivento by grouping all the stakeholders of the territories and beyond with skills and experience in Digital Transformation and wants to be the enabling platform that allows the entire production and social system to face the future and create value in the process.

  SMACT spreads 4.0 skills with high, practical, and focused training, with excellent research and the most innovative companies. From Digital Transformation Training for managers and entrepreneurs to ITS on cyber security and machine learning, passing through custom courses built on the needs of companies and students.
- **Meditech**[28] (Meditech Consortium – Mediterranean Competence Center for Innovation): is the Competence Center that targets the use of Enabling Technologies of the 4.0 Industry towards the diffusion of innovation practices in the production of goods and services on the national territory and in particular within the Mediterranean basin. MEDITECH intends to focus on: Business orientation, Business Training, Implementation of innovation projects, industrial research, and experimental development. Meditech implements a "Teaching Factory 4.0" which is capable of: preparing informative material and promoting disclosure of initiatives on technologies and solutions in the 4.0 Industry, planning and delivering training for all professional activities of the various corporate functions, to offer interested companies an innovation process by using pilot systems for testing and verifying 4.0 solutions.

- **START4.0**[29]**:** Start4.0 activities focus on five application domains: ENERGY - TRANSPORT - WATER - PRODUCTION - PORT, through the application and development of solutions that refer to a subset of Industry 4.0 enabling technologies declined with respect to a specific application, that of the protection of strategic infrastructures and their optimized design. The Competence Center will develop its actions by referring to all possible declinations of security, namely: Safety, Security, and, of course, Cyber Security. Artificial Intelligence & Machine Learning, Augmented Reality & Virtual Reality, Agile Methodology & Organizational Paradigms, Cybersecurity, Open Innovation, Cloud, and Design Thinking & Service Design were among the main topics of training in 2021 in this competence center.

- **CYBER 4.0**[30] (Cybersecurity Competence Center): CYBER 4.0 is the expression of a composite, interdisciplinary and multi-actor public-private partnership, which covers a wide spectrum of skills and promotes the development of a network of qualified collaborations, to support the provision of guidance and training services, and the development of research and innovation projects. this competence center provides training courses on cyber risk management both in the preventive and response phases, on cybersecurity compliance and governance, including the management of IT service supply contracts, which will be made available for managers and entrepreneurs. In addition, an e-learning platform

[27] https://www.smact.cc/?lang=en
[28] http://meditech4.com/
[29] https://www.start4-0.it/
[30] http://www.cyber40.it/

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 873086.

dedicated to training non-technical users (Cyber Security Awareness) will be created. there are two main streams about these courses: Awareness-raising initiatives and Specialist courses.

Besides Competence Centers, the Industry 4.0 Plan supported the creation of the **Italian DIHs by Confindustria [31]:** Confindustria has offered a decisive contribution to the strategy of the Transition Plan 4.0 (formerly the National Industry Plan 4.0), developing an articulated package of proposals that the Government has largely incorporated into the Plan with automatic fiscal and financial tools to support the digital transformation of the production system. One of the main critical parts of this center is related to Training4.0 which covers different area of I4.o such as IoT, robotics, cloud computing… This center provides different education methods; Webinar, E-learning, i4.0 quiz, classrooms, etc.

In addition to the items mentioned in the previous paragraphs, it's worth also to mention public incentives such as the "Training tax credit 4.0[32]". Here we intend to mention "**Training tax credit 4.0**" that is more related to I4.0 training activity. The measure is aimed at supporting companies in the process of technological and digital transformation by creating or consolidating the skills in enabling technologies necessary to achieve the 4.0 paradigm. Eligible training activities are about Training Issues 4.0 such as big data and data analysis, cloud and fog computing, cyber security, simulation and cyber-physical systems, rapid prototyping, etc. Advantages of this incentive are about recognition of tax credit to the extent of 50% of eligible expenses for micro and small enterprises, 40% of eligible expenses for medium-sized enterprises, 30% of eligible expenses for large companies. These eligible expenses are related to personnel expenses related to trainers for the hours of participation in the training, operating costs related to trainers and training participants directly connected to the training project, such as travel expenses, materials and supplies directly related to the project.

3.2.7.2 ITS[33] (Istituti Tecnici Superiori) - Higher Technical Education Institutes

The main goal of these VET schools is to train professionals with the technical skills most requested by companies, ready to enter the world of work. The courses last a total of two years and are usually divided into semesters, from four to six, for a total of 1800/2000 hours. They have a very practical setting, with internships (possibly even abroad) for at least 30% of the total hours and teachers from companies, ready to share their experience. ITS courses allow people to have an internship experience in a company: during this period of professional training, students can experience the skills acquired directly in the field and to contribute to the development of corporate digitalization processes, thanks to the knowledge and to the innovative dynamics of the Higher Technicians.

[31] https://preparatialfuturo.confindustria.it/formazione/
[32] https://www.mise.gov.it/index.php/it/incentivi/impresa/credito-d-imposta-formazione
[33] https://sistemaits.it/?p=home

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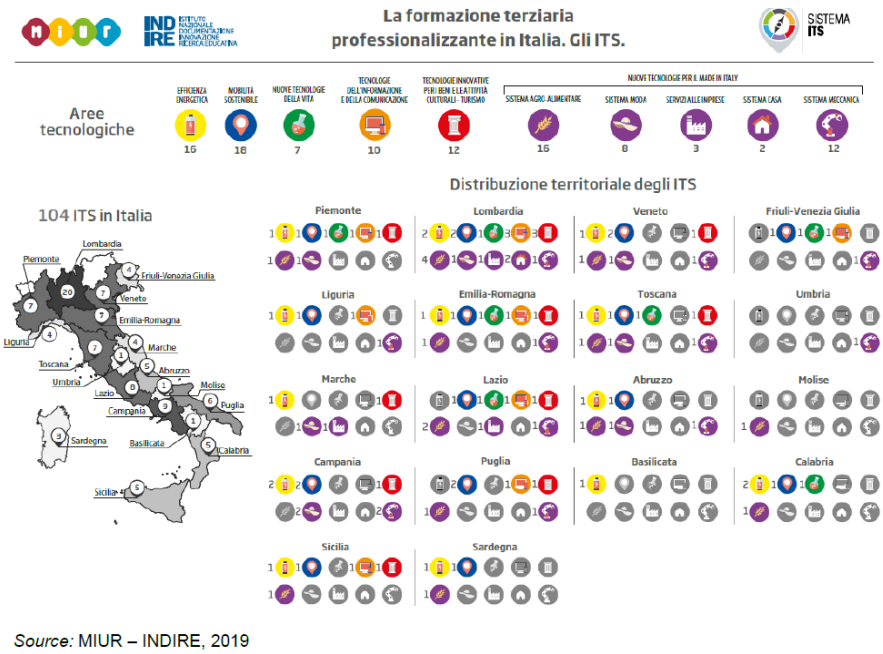

Figure 5: Professionalizing tertiary education in Italy

Examples of Italian ITS focused-on Industry 4.0:

- **ITS Lombardia Meccatronica[34]:** This institution mainly provides courses related to industrial mechatronics, maintenance systems for I4.0, product, and processes of industrialization such as: two years ITS course in industrial Mechatronics, two years ITS courses in Railway Mechatronics, Biomedical Mechatronics, Sustainable motor vehicles mechatronics, maintenance of mechatronic systems for I4.0, and product & process industrialization.

- **ITS Emilia Romagna[35]:** The ITS Emilia Romagna Polytechnic School Association brings together the seven ITS Foundations of the Emilia Romagna region, in order to develop shared strategies to be even more organized and competitive in promoting training, stimulating talent, suggesting career paths, and facilitating entry into the world of work (primary and fundamental objective) in a system at the service of the citizens of Emilia-Romagna. The network is also a single point of reference for the Region, local authorities, universities, the school and training system, businesses, innovation centers, local social actors. A tool for development and action, which facilitates the representation of the seven ITS Foundations, allowing them to keep up to date with the changing educational trajectories and to strengthen the relationship with institutional and non-institutional realities active in the territory. These seven ITS foundation and main topics of courses are about: Tourism marketing, Mobility and logistics, Mechanics, automation and packaging, Argo-food chain management, Digital technologies and fashion, Production of biomedical devices, and Sustainability and energy efficiency.

[34] https://www.itslombardiameccatronica.it/
[35] https://itsemiliaromagna.it/

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3.2.7.3 Universities

Due to space constraints and the large number of universities that offer special programs in the field of I4.0, in this section, we only mention three main polytechnic universities in Italy:

- **Politecnico di Milano[36]:** The Politecnico di Milano is the largest technical university in Italy. In its undergraduate, graduate, and lifelong learning programmes, this university offers several programs related to I4.0 and I5.0 subjects. Listed below are a few of them.
  - **Master of Science in Management Engineering[37]:** Management Engineering aims to train engineering professionals ready to address today's business problems with innovative solutions. This program offers the opportunity to really integrate high-level management skills with in-depth technical competencies, enabling students to deal with complex systems in many different areas such as Industry 4.0[38] and Circular economy[39] Stream.
  - **New Master of Science Degree in Cyber risk strategy and Governance[40]**; Two of Italy's most prestigious universities, Bocconi[41] and Politecnico di Milano, have joint forces to prepare a new category of professionals in the field of cyber risk. The two-year program is based on a complementary blend of their strengths: Politecnico provides top-flight technological training, while Bocconi shares its expertise on the strategic and economic fronts. Firstly, it offers technical competencies in the fields of computer science and technology, crucial to a deep understanding of the cyber world. Then it reviews managerial, legal, and economic principles to place cyber risk into context.
  - **EIT Manufacturing's Master Programmes[42]:** The EIT Manufacturing Master School aims to attract and empower top talents with cross-border and cross-sectorial mobility and other learning opportunities that help them become leading manufacturing innovators and entrepreneurs. It offers mobility, mentorship, networking, innovation, and entrepreneurship, including relevant training on how to transform ideas into businesses. In particular, this program shows learners how to develop business models, business cases, and business plans. To achieve the goals set in this school, many universities, including the top two Italian universities Politecnico di Milano and the University of Trento[43] are collaborating together. Among the courses covered by this center, the following can be mentioned: Data Science and AI for Manufacturing, digitalizing value networks, Zero-Defect Manufacturing for a Circular Economy.

  In addition, Politecnico di Milano also has several programs for professionals and life-long learning, e.g.:
  - **Digital Innovation Observatories of the School of Management[44]:** These observatories provide an expert point of reference for digital innovation, performing research, communication, and continuous update activities. Its purpose is to generate and spread knowledge about opportunities and the impact of digital technology in companies, public authorities, and the citizens. Critical areas

[36] https://www.polimi.it/
[37] https://www2.polimi.it/index.html%3Fid=8995&L=1.html
[38] https://www4.ceda.polimi.it/manifesti/manifesti/controller/ManifestoPublic.do?check_params=1&aa=2021&k_corso_la=479&lang=EN&k_indir=I40&polij_device_category=DESKTOP&__pj0=0&__pj1=9e37952d14cf9a1e9a74cb3781d816e5
[39] https://www4.ceda.polimi.it/manifesti/manifesti/controller/ManifestoPublic.do
[40] https://www.polimi.it/en/international-prospective-students/laurea-magistrale-programmes-equivalent-to-master-of-science/programme-catalogue/cyber-risk-strategy-and-governance/
[41] https://www.unibocconi.it/wps/wcm/connect/Bocconi/SitoPubblico_IT/Albero+di+navigazione/Home/
[42] https://www.eitmanufacturing.eu/what-we-do/education/education-programmes/empower-programme/master-school/
[43] https://www.unitn.it/
[44] https://www.osservatori.net/en/home

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 873086.

cover by this observatory related to I4.0 and I5.0 are AI, Cloud computing, Big Data Analytics & Business Intelligence, Internet of Things, Blockchain, etc.
In the last years one specific Observatory has been focused on Industry 4.0. The **Industry 4.0 Observatory** is a point of reference in Italy for managers and decision-makers with a need to thoroughly understand digital innovations (processes, infrastructure, applications, hardware and software) that are, transforming the manufacturing sector, codifying and making knowledge more accessible, and creating an Italian community that is active and open to comparison with international practices.

- **MIP Business School[45]:** The MIP Management Academy is designed specifically for those who already have consolidated work experience and who are grappling with a rather demanding working life but feel the need to acquire or improve their skills in key areas of management knowledge. Among the courses covered by this center, the following can be mentioned: International master in smart operations and industry 4.0, International master in Cybersecurity management, international business and digital transformation, Global executive master in operations and supply chain, and international master in big data. **FLEXA[46]** is MIP Politecnico di Milano's innovative, personalized, continuous learning platform, featuring the latest Microsoft artificial intelligence tools. This new digital mentor allows professionals to bridge their skills gaps and expand their expertise in a personalized way.

Innovative Pedagogical approaches and Knowledge Delivery Mechanisms are exploited in Politecnico di Milano's programmes on I4.0, such as:

- **Learning Factory:** The Industry 4.0 LAB[47] of Politecnico di Milano is a learning factory used to provide education and training programs to students and workers and involved in projects such as Industry 4.0 student contest 2021[48] to improve skills in the area of Industry 4.0 communication architectures, Data analysis, and Development of solutions for production sectors such as predictive maintenance, machine monitoring, production scheduling, energy monitoring. Furthermore, this Lab also collaborates in funded projects such as AI REGIO[49], LIFT[50], EIT Manufacturing[51] to create Learning Factory Networks where Politecnico di Milano and MADE competence center are involved.
- **Teaching Factory:** Politecnico di Milano also participate in EIT Manufacturing funded projects such as TFKnowNet[52] focused on the teaching factory concept where its students are involved in challenge launched by industries.
- **Young manufacturing leader (YML)[53]:** Young Manufacturing Leaders is an open initiative for students, young workers and professionals interested in a career in the manufacturing sector. The initiative is strongly committed to raise awareness about the possibilities in manufacturing, and to spread knowledge of the skills needed in this sector. It supports all members with different activities,

[45] https://www.som.polimi.it/en/course/management-academy/
[46] https://www.som.polimi.it/en/flexa/
[47] https://www.industry40lab.org/
[48] https://www.fondazionepolitecnico.it/progetti/industria-4-0/mindsphere-world/
[49] https://www.aireqio-project.eu/
[50] U.D Atmojo, W. Quadrini, V. Nucera, P. Pedrazzoli, M. Fiorello, "Creating a methodology to train manufacturing SMEs: the LIFT Europe case", 11th Conference on Learning Factories, CLF2021 https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3862463
[51] https://www.eitmanufacturing.eu/
[52] https://tfknownet.com/
[53] https://youngmanufacturingleaders.org/

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 873086.

such as peer-to-peer seminars, mentorship with professionals and entrepreneurs, and participation to the activities of the World Manufacturing Foundation.

- **Politecnico di Torino[54]:** Politecnico di Torino is an Italian state university, specialized in engineering, architecture and design. In addition to undergraduate, graduate, and higher education courses, this university also offers several programs related to Manufacturing4.0[55], Industry 4.0 for production systems[56], Data science and engineering[57]. Some examples of courses focused on additive manufacturing and addressing different target groups are reported in the figure below.

Politecnico di Torino

- **Politecnico di Bari[58]:** The Politecnico University of Bari is an Italian state university, where in addition to undergraduate, graduate, and higher education courses, this university also offers several laboratory activities such as: the Information Systems Laboratory (SisInf Lab)[59] which main competencies and research activities are about Artificial Intelligence, Smart Manufacturing, Industry 4.0, Machine Learning, Big Data Analysis, and Information Systems; the Telematics Laboratory[60] where the main Competencies and research activities are internet of Things (IoT), Nano-networks, 5G systems, Network Measurements; the Industry 4.0. AVLAB - Artificial Vision Laboratory[61], where research activities are about engineering and installation of smart vision systems aiming to automate industrial processes (Industry 4.0, quality controls, ...), perform diagnostics and provide security.

3.2.8 The Netherlands

3.2.8.1 National level initiatives offering education and training for industry 4.0

Smart Industry[62] is an initiative founded in November 2014 by the Dutch Ministry of Economic Affairs in cooperation with TNO, the Dutch Chamber of Commerce (KVK), the Royal Metal Union (Koninklijke Metaalunie), FME and regional development companies in the Netherlands (ROMs). It encourages companies to apply smart technology and make use of digitization to create new business opportunities. Since 2018,

[54] https://www.polito.it/?lang=en
[55] https://didattica.polito.it/master/manufacturing_4_0/2019/at_a_glance
[56] https://didattica.polito.it/pls/portal30/gap.pkg_guide.viewGap?p_cod_ins=02USOLO&p_a_acc=2022&p_header=S&p_lang=&multi=N
[57] https://didattica.polito.it/pls/portal30/sviluppo.offerta_formativa.corsi?p_sdu_cds=37:320&p_a_acc=2022&p_header=N&p_lang=EN
[58] http://www.poliba.it/
[59] http://www.en.poliba.it/research/information-systems-laboratory-sisinf-lab
[60] http://www.en.poliba.it/research/telematics-laboatory
[61] http://www.en.poliba.it/research/avlab-artificial-vision-laboratory
[62] https://smartindustry.nl/organisatie

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Smart Industry has been also tasked with putting into practice the Implementation Agenda[63] 2018-2021. Among other sub-initiatives, Smart Industry Hub North is tasked with setting up skills development labs.

Skills Lab North

The Skills Labs train both employees and students in digital competences. The labs are (currently being) set up as a collaboration between Dutch companies and educational institutions – secondary vocational education (MBO), higher professional education (HBO) and the universities. There are three Skills Labs planned in the Northern Netherlands: in Drachten (focusing on smart products), Groningen (focusing on artificial intelligence) and Emmen (focusing on smart manufacturing).[64] All three labs are also intended as demo locations – participating companies can test and view the smart solutions as they are being tried out.

The Skills Lab in Drachten is the first one among the three labs to be officially launched. It started in October 2020 and is set up in the form of a menu from which manufacturing and process industry companies (large and small but also start-ups) that focus on smart products can choose on what digital skill to focus. Participation in the lab is usually free. The lab as such is intended as a knowledge exchange platform for the participating companies which can actively learn both from each other's skills and innovation techniques, as well as by investing in the formation of the next working generation. For the time being, there are 23 companies participating that share knowledge with each other. The knowledge sharing for students is currently in the shape of honors programs and High-tech Safaris (that give students a first peek behind the scenes).[65] There are also special career and development programs for talents.

Other institutions

Outside of the Skills Labs North which are only starting to take shape, there are a couple of industry 4.0–dedicated educational programs that are noteworthy. One of them is being offered at the Graafschap College[66] in the shape of a Middle Management Smart Industry profile. The latter combines elements from the already existing programs that the College offers in the fields of control technology, ICT, application development and industrial engineering. Students are thus introduced to robotics, control technology, Internet-of-Things, embedded systems, etc.; learn to program in different programming languages, to use the Raspberry Pi and acquire further knowledge about controlling, reading and making smart devices. Part of the four-year trajectory are also courses on technical business administration and management, combined with internships at regional companies.

Lastly, the SUMMA College[67] has just launched a vocational training trajectory for Smart Industry technicians. As Smart Industry technicians, students learn to design, program and test embedded electronics. During their training they thus learn about components such as sensors and actuators, and about control technology such as microcontrollers and PLCs. Communication and control protocols (internet of things) are also discussed, as well as big data and robotics. Smart Industry technician are prepared to have both an executive and a supervisory role. There are two possible training routes - a 2-year-long and a 3-year-long variant.

[63] *According to the Implementation Agenda 2018-2021, the Netherlands should have the most flexible and best digitally connected production network in Europe by 2021, by means of which manufacturing companies also realize substantial energy and material savings. The intended results are of the Agenda were: 1) more economic growth by increasing productivity; 2) more employment and attractive jobs and 3) contributing to solving social issues through, for example, less use of raw materials and energy.*
[64] *Skillslab - Smart Industry*
[65] *Part of the smart - ICDishes (icdrachten.nl)*
[66] *Middenkaderfunctionaris Smart Industry - Graafschap College*
[67] *Technicus Smart Industry (bbl) (summacollege.nl)*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 873086.

3.2.9 Sweden

Produktion2030[68] is a strategic innovation programme supported by Vinnova, the Swedish Energy Agency and Formas. Its goal is to ensure that Sweden remains a competitive manufacturing nation. Initiated by the Production2030 program, Sweden has developed a major program for manufacturing education called "Engineer / Ingenjör 4.0"[69] where a large network of universities offers manufacturing industries upskilling and reskilling in Industry 4.0 topics. Ingenjör4.0 is an upskilling program aimed for professionals with an engineering background. It offers to individual and companies to take part in our web-based learning modules, led by teachers from Swedish universities, that will enable the development of knowledge and skills sets needed for digital and smart manufacturing. Ingenjör4.0 modules take about 4 hours per week over 5 weeks to complete. They follow clear learning paths with time estimations of each chapter and the studies can in most parts be spent at the learner's convenience. A few webinars are scheduled in each module where you engage in deeper discussions on selected topics, together with teachers and co-learners. The education program offers several modules such as Additive Manufacturing, Autonomous Robots, Smart Maintenance, AR/VR and many more.

3.2.10 UK

3.2.10.1 Introduction to I4.0 Training in the UK

Due to the political governance of the UK, the training landscape varies across the four home nations (i.e., England, Scotland, Wales, and Northern Ireland). While there is some commonality between the approaches, there is no official coordinated approach for the UK as a whole.

In addition to this, many training initiatives are devolved to the local government level (i.e., the councils that govern the counties that constitute each nation) or are targeted at specific reasons to improve regional skills. Opportunities that are present in (for example) the North West of England[70] may not be accessible to other regions.

Training is generally offered by three classes of institution:

- **Central government** i.e., the governments of the United Kingdom (commonly referred to as Westminster and has jurisdiction over England and some limited elements of the other home nations), the Scottish Government, the Welsh Government, and the Northern Irish Executive. The education departments of each nation are entirely separate.
- **The Public Sector** i.e., government-funded research institutes and universities.
- **The Private Sector** i.e., private companies.

"Industry 4.0" is not as common a term within the UK as it is in mainland Europe. "Digital Manufacturing", "Smart Manufacturing" and the use of "Industrial Digital Technologies" are common synonyms, mainly emerging from the Made Smarter Review[71], the most influential report on digital manufacturing in the UK.

[68] Produktion2030, https://produktion2030.se/
[69] Ingenjör 4.0, https://www.ingenjor40.se/
[70] https://www.madesmarter.uk/resources/publication-made-smarter-technology-adoption-pilot-report/
[71] https://www.gov.uk/government/publications/made-smarter-review

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3.2.10.2 Government initiatives and Reports

In general terms, the England Department for Education has published its recommendations for skills for jobs in context of lifelong learning[72] in January 2021 and highlighted the importance of continued education in skills.

"From September 2020 to March 2021, we are investing £8 million to train adults in digital skills through an innovative, employer-led digital training initiative, helping adults of all ages to learn IT skills. Employers will select, or co-design with providers, short and flexible training lasting between 12 and 16 weeks which will meet critical skills needs and help adults to retrain, top up skills, or gain new specialist skills",

"We will start by delivering digital bootcamps in six areas: West Midlands, Greater Manchester/Lancashire, Liverpool City Region, West Yorkshire, East Midlands, and the Southwest. […] We will use up to £43 million in 2021/22 to expand the digital bootcamps from April 2021".

These bootcamps are free courses for adults in the UK and are offered in combination with universities and other training bodies[73]. Relevant courses include Artificial Intelligence and Machine Learning, Data Science and Data Engineering, Cloud computing and Cloud Engineering, and Cybersecurity, but none of the courses are specific to the manufacturing domain.

Local Enterprise Partnerships (LEPs) are regional development organisations designed to assist local businesses with funding and training. For example, the University of Nottingham lies within the D2N2 LEP[74] (Derby, Derbyshire, Nottingham, Nottinghamshire), which offers subsidised training to businesses on topics such as Data Security and Protection Training[75]. Currently, the training offered is general, and less applicable to Industry 4.0. D2N2 offers the aforementioned bootcamps, including programming, cyber security, and IT networking[76].

One of the principal outcomes of the Made Smarter Review and Made Smarter Initiative was the Enginuity platform[77], an aggregator for digital manufacturing information. This platform gathers insights and opportunities in the digital manufacturing domain. Importantly, it also gathers online training courses on Industry 4.0 topics from industry in one place, allowing easier access to an otherwise fragmented training landscape.

The Government of Wales has published many reports that are focused on or discuss Industry 4.0, including *Wales 4.0: Delivering Economic Transformation for a Better Future of Work*[78], *Skills for the Future: What the Future Generations Report 2020 Means for the Welsh Government Post-16 Education Team*[79], and *Shaping the Future: A 21st Century Skills System for Wales*[80] which all recommend Industry 4.0 or related skills as critical for Wales. However, other than the Made Cymru: Upskilling for Industry 4.0 programme[81], little evidence of a coordinated government approach to training could be found.

[72] https://www.gov.uk/government/publications/skills-for-jobs-lifelong-learning-for-opportunity-and-growth
[73] https://www.gov.uk/government/publications/find-a-skills-bootcamp/list-of-skills-bootcamps
[74] https://d2n2skillsaccesshub.co.uk
[75] https://d2n2skillsaccesshub.co.uk/news/data-security-and-protection-training
[76] https://d2n2lep.org/people-skills/skills-bootcamps/
[77] https://enginuity.org/innovation-lab/engage/
[78] https://gov.wales/sites/default/files/publications/2019-09/delivering-economic-transformation-for-a-better-future-of-work.pdf
[79] https://www.futuregenerations.wales/wp-content/uploads/2021/08/ENG-Bitesize-WG-post-16-NEW.pdf
[80] https://www.ippr.org/files/2020-01/shaping-the-future-wales-feb20.pdf
[81] https://www.madecymru.co.uk/project/upskilling-for-industry-4-0wales/

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The Government of Scotland's *Skills 4.0: A Skills Model to Drive Scotland's Future* report[82] emphasises the need for Industry 4.0 skills training. The National Manufacturing Institute Scotland offers a variety of manufacturing courses, with relevant Industry 4.0 courses including Internet of Things[83], and Extended Reality[84]. The Scottish Manufacturing Advisory Service (SMAS) will aid companies with an Industry 4.0 review, but does not offer training on the topic directly, instead focusing their training on continuous improvement tools and techniques[85].

The Northern Ireland Executive's Department for the Economy specified in their Skills Strategy[86] that developing digital skills was a key priority, and that "*Skills policy is also set in the context of an uncertain future, driven by the emergence of Industry 4.0*". A Skills Council is to be created to manage development in this area, but out literature review turned up little evidence of progress on this. The Northern Ireland Executive runs their Assured Skills Academies[87] for training un-employed or under-employed workers, with digital skills and big data engineering being two relevant courses listed. Previous courses have included cyber security and data analytics, showing that they identify these skills as priority areas.

3.2.10.3 Public sector initiatives

An additional outcome of the England Department for Education skills report is:

"We will fund the High-Value Manufacturing Catapult's 'Skills Value Chain'. This process assesses future skills needs in manufacturing, develops courses to meet these needs, and makes those courses widely available through high-quality providers such as Institutes of Technology. It will support Small and Medium Enterprises (SMEs) to work with emerging technologies in the manufacturing sector, such as electrification, additive manufacturing, and metrology".

The High Value Manufacturing Catapult (HVMC) is a centre for innovation that harnesses technology advancements and bridges the gap between academia and the private sector. Connected Factories partner The Manufacturing Technology Centre is one of seven centres that collectively comprise the Catapult.

To address the Skills Value Chain, the HVMC investigated the workforce crisis in UK manufacturing with their "*Manufacturing the Future Workforce*" report[88]. A key outcome of this report is the creation of the Emerging Skills Project[89], designed to deliver training in cutting edge technologies for all manufacturing businesses. These are short courses on additive manufacturing, composites, electrification, industrial digitalisation technologies, and a series of courses for trainers to improve their skills.

In addition to the coordinated Manufacturing the Future Workforce project, many HVM centres also offer their own training courses in their specialist areas. The majority are not relevant to Industry 4.0, with the following exceptions:

- **The Manufacturing Technology Centre** (MTC) through their Advanced Manufacturing Training Centre (AMTC)[90]: Additive manufacturing, automation and robotics, business improvement, digital construction, digital manufacturing, laser processing, and leadership and management.

[82] *https://www.skillsdevelopmentscotland.co.uk/media/44684/skills-40_a-skills-model.pdf*
[83] *https://www.nmis.scot/nmis-group/manufacturing-skills-academy/continuous-professional-development/internetofthings/*
[84] https://www.nmis.scot/nmis-group/manufacturing-skills-academy/continuous-professional-development/introductiontoextendedrealitycourse/
[85] *https://www.scottish-enterprise.com/support-for-businesses/develop-products-and-services/support-for-manufacturers*
[86] *https://consultations.nidirect.gov.uk/dfe/skills-strategy-for-northern-ireland/user_uploads/full-version-skills-strategy.pdf*
[87] *https://www.nidirect.gov.uk/articles/assured-skills-training-programme*
[88] *https://hvm.catapult.org.uk/mtfw/*
[89] *https://emergingskillsproject.com/*
[90] *https://the-amtc.co.uk/training/*

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- **The Warwick Manufacturing Group** (WMG), part of Warwick University[91]: Data-driven Smart Manufacturing, Demystifying Digital Twins, Industry 4.0 Integration and Implementation, and Manufacturing Awareness.
- **The National Composites Centre** (NCC): Offers a wide range of training on composites manufacturing, but also a course on Digital Learning Factories[92] as part of a regional initiative called Workforce for the Future[93], funded by the European Social Fund[94].

Most Universities in the UK will offer undergraduate and postgraduate degree courses that include relevant modules, such as a Digital Manufacturing module offered by the University of Nottingham for their manufacturing engineering courses. Dedicated Smart Manufacturing and Intelligent Manufacturing systems masters' courses do exist, such as those offered by Birmingham City University[95], Ulster University[96], and Warwick University[97]. Continued professional development is generally not offered by Universities directly, but training courses and seminars are sometimes organised as part of research projects and networks such as the Connected Everything network[98], the Institute of Coding[99], the Digital Manufacturing on a Shoestring project[100], and in European projects such as Digit-T[101].

An additional avenue is through the Knowledge Transfer Network[102], which is government funded through Innovate UK[103], which seeks to connect industry with innovators (other companies, academic, and individuals) and with funding opportunities across a wide range of topic areas, including manufacturing. Though primarily a way to fund innovation and development projects, the KTN also offers way to fund training opportunities to accelerate innovation.

3.2.10.4 Private sector initiatives

A wide range of private sector training opportunities exist for Industry 4.0 training in the UK, but the landscape is highly fragmented and variable. While initiatives such as the Enginuity Engage platform bring some training together, there is no simple way to identify training opportunities other than a web search.

Large manufacturing equipment providers such as Festo can have dedicated training providers, in this case Festo Didactic, offering a wide range of paid-for training on Industry 4.0 topics[104]. The advantage of these courses is the ability to have hands-on experience with industrial automation products. There are many examples of companies offering training for their products (such as Beckhoff[105], Siemens[106], KUKA[107], ABB[108]) but most offer training for Industry 4.0 in context of their specific products, rather than Industry 4.0 in general.

[91] https://warwick.ac.uk/fac/sci/wmg/skillscentre/courses/
[92] *https://www.nccuk.com/training/workforce-for-the-future-digital-learning-factories/*
[93] *https://www.westofengland-ca.gov.uk/what-we-do/employment-skills/workforce-for-the-future/*
[94] *https://ec.europa.eu/european-social-fund-plus/en*
[95] *https://www.bcu.ac.uk/courses/smart-manufacturing-msc-2022-23*
[96] *https://www.ulster.ac.uk/courses/202223/smart-manufacturing-systems-28387*
[97] *https://warwick.ac.uk/study/postgraduate/courses/intelligentsystems/*
[98] *https://connectedeverything.ac.uk/*
[99] *https://instituteofcoding.org/courses/search/*
[100] *https://www.digitalshoestring.net/*
[101] *https://www.digit-t.eu/*
[102] *https://ktn-uk.org/*
[103] *https://www.ukri.org/councils/innovate-uk/*
[104] *https://instituteofcoding.org/courses/search/*
[105] *https://www.beckhoff.com/en-gb/support/training-offerings/*
[106] *https://www.sitrain-learning.siemens.com/IN/en/rw16629/Introduction-to-Industry-4.0*
[107] *https://www.kuka.com/en-gb/services/kuka-college*
[108] *https://new.abb.com/service/abb-university*

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3.2.10.5 Conclusions

The Industry 4.0 training landscape in the UK is a complex one. The UK is a "country of countries", and the skills agenda for each constituent nation is devolved to that nation's government. As a result, there are different approaches and priorities for England, Wales, Scotland, and Northern Ireland which must be considered. Even within a single nation, training can be further devolved to the local government level, with training offered by LEPs and councils. In general, government funding for training is focused on general digital skills rather than specific Industry 4.0 ones, with the Made Smarter government project being the focus for digital manufacturing-specific training.

There are a wide range of opportunities for knowledge delivery in the public sector, but each University or Catapult Centre will approach this differently, and even within a single institute different projects and networks will have different approaches to training and skills exchange.

Many paid-for private sector training offers are available, though most companies large enough to offer such dedicated training offers are multinationals, and thus the opportunities are not UK specific. Many large manufacturing companies offering training have UK offices however, allowing learners to attend hands-on sessions.

The UK is at an advantage of having a majority English-speaking population, and thus can take advantage of a wide range of online international training courses more than many other countries, especially when a knowledge of technical English is required.

4 Conclusions and Future Outlook

The exploration of knowledge delivery mechanisms and business models for upskilling and reskilling has indicated that several approaches are employed from both the business and the technical or methodology point of view. From technology and method point of view there are several knowledge delivery systems/mechanisms employed.

- Courses of vocational training (both remotely and online) are active in many cases such as those requiring access to physical equipment.
- MOOC and Learning and Training online nuggets are very popular for the needs of microlearning and are being utilized by platform initiatives such as skills.move of the EIT Manufacturing the Digital Skills and Jobs platform of the Digital Europe Program.
- Games and Gamification approaches although have merit is some specific cases, they are in principle costly to be developed and maintain.
- Virtual and Augmented reality are employed by several initiatives as their development cost and maintenance costs have decreased and several off-the-self AR/VR equipment is available. The shift to the so-called Metaverse[109], if going to be achieved in the scales envisioned by its originators, will certainly further boost the se of VR/AR technologies for learning and training.
- Teaching and Learning factories are certainly getting a lot attention especially in the case of university, labs and competence centers are the ones offering the L&T sessions.

[109] Meta- metaverse, https://about.facebook.com/meta/ accessed online May 2022

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- On the job training remains popular and can be combine with advanced technologies such as IoT and AR.

On several occasions, there is a combination of technologies that fit to the overall education program or learning paths. For example, there are cases in which learning and training nuggets are combined with teaching or learning factory approaches.

From business point of view there are several entities offering lifelong learning (upskilling and reskilling) services. Traditional organizations such as universities and training centers have a vital role in the L&T process as they provide the fundamental competencies need. However, relatively new entities such as EDIHs, Competence Centers, Digital Europe Program and the education pillar of EIT-Manufacturing create a new set of L&T opportunities that are combined with a holistic set of services to companies, such as SME, including testing of equipment and technical services, business creation and incubation as well as networking and access to markets and ecosystems.

Looking at the current landscape in L&T knowledge delivery mechanism and the needs for upskillg and reskilling in advanced manufacturing (see Reskilling needs in Advanced Manufacturing according to WEF 2020 report[110]) it can be concluded that more support to innovative life-long learning approaches is required together with supporting advanced technology developments such as AR/VR and their L&T applications in manufacturing. EU should also take stock of the (E)DIH network in order to promote skills development and create synergies with manufacturing focused initiatives such EIT Manufacturing and Made In Europe manufacturing partnership of EFFRA with the European Commission under the Framework Programme 'Horizon Europe'.

References

Abele, E., Chryssolouris, G., Sihn, W., Metternich, J., ElMaraghy, H., Seliger, G., ... & Seifermann, S. (2017). Learning factories for future oriented research and education in manufacturing. *CIRP annals*, *66*(2), 803-826.

Alipour, M., Salehi, M., &Shahnavaz, A. (2009). A study of on the job training effectiveness: Empirical evidence of Iran. *International journal of business and management*, *4*(11), 63-68.

Badurdeen, F., Marksberry, P., Hall, A., & Gregory, B. (2010). Teaching lean manufacturing with simulations and games: A survey and future directions. *Simulation & Gaming*, *41*(4), 465-486.

Baena, F., Guarin, A., Mora, J., Sauza, J., & Retat, S. (2017). Learning factory: The path to industry 4.0. *Procedia manufacturing*, *9*, 73-80.

Bardy, S., Cibis, K., Hoppe, S., Schubert, T., Szuppa, S., Biscardo, G., & Metternich, J. (2021). Human in the AI loop: Teaching shop floor workers artificial intelligence in production. *Giacomo and Metternich, Joachim, Human in the AI Loop: Teaching Shop Floor Workers Artificial Intelligence in Production (June 8, 2021)*.

Barzegar, N., &Farjad, S. (2011). A study on the impact of on the job training courses on the staff performance (a case study). *Procedia-Social and Behavioral Sciences*, *29*, 1942-1949.

Bender B, Kreimeier D, Herzog M, Wienbruch T (2015) Learning Factory 2.0—Integrated View of Product Development and Production. 5th CIRP-sponsored Conference on Learning Factories, Procedia CIRP 32: 98-103.

[110] World Economic Forum, 2020, The Future of Jobs Report, October 2020

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 873086.

J.K. Bologna, C.A. Garcia, A. Ortiz, P.X. Ayala, M. v. Garcia, An Augmented Reality Platform for training in the industrial context, IFAC-PapersOnLine. 53 (2020) 197–202.

Bordegoni, M., Carulli, M., and Spadoni, E. (December 10, 2021). "Multisensory Virtual Reality for Delivering Training Content to Machinery Operators." ASME. J. Comput. Inf. Sci. Eng. June 2022; 22(3): 031003. https://doi.org/10.1115/1.4053075

Chryssolouris, G., Mavrikios, D., & Rentzos, L. (2016). The teaching factory: a manufacturing education paradigm. *Procedia Cirp*, *57*, 44-48.

G. Chryssolouris, D. Mavrikios, D. Fragos, V. Karabatsou, K. Pistiolis, "A Novel Virtual Experimentation Approach to Planning and Training for Manufacturing Processes-The Virtual Machine Shop", International Journal of Computer Integrated Manufacturing, Volume 15, No.3, pp. 214-221 (2002)

D. Mourtzis, J. Angelopoulos, G. Dimitrakopoulos, “Design and development of a flexible manufacturing cell in the concept of learning factory paradigm for the education of generation 4.0 engineers”, 10th Conference on Learning Factories (CLF 2020), Procedia Manufacturing, Volume 45, pg. 361-366, 15-17 April, Graz, Austria (2020)

D. Mourtzis, V. Siatras, J. Angelopoulos, N. Panopoulos, “An Augmented Reality Collaborative Product Design Cloud-Based Platform in the Context of Learning Factory”, 10th Conference of Learning Factories (CLF 2020), Procedia Manufacturing, Volume 45, pg. 546-551 , 15-17 April, Graz, Austria (2020)

Djaouti, D., Alvarez, J., Jessel, J. P., & Rampnoux, O. (2011). Origins of serious games. In *Serious games and edutainment applications* (pp. 25-43). Springer, London.

Dodson, M. N., Kitburi, K., & Berge, Z. L. (2015). Possibilities for MOOCs in corporate training and development. *Performance Improvement*, *54*(10), 14-21.

E. Tzavara, P. Angelakis, G. Veloudis, C. Gkournelos, S. Makris, “Worker in the loop: a framework for enabling Human-Robot collaborative assembly”, Advances in Production Management Systems Conference (APMS), Volume 630, pg. 275-283 , 5-9 September, Nantes, France, 2021

Eder, M., Hulla, M., Mast, F., Ramsauer, C., On the application of Augmented Reality in a learning factory working environment, Procedia Manufacturing, Volume 45, 2020, Pages 7-12, ISSN 2351-9789, https://doi.org/10.1016/j.promfg.2020.04.030.

Euler, D. (2013). Germany's dual vocational training system: a model for other countries?.

Görke, M., Bellmann, V., Busch, J., &Nyhuis, P. (2017). Employee qualification by digital learning games. *Procedia Manufacturing*, *9*, 229-237.

Hanushek, E. A., & Wößmann, L. (2007). The role of education quality for economic growth. *World Bank policy research working paper*, (4122).

Hauge, J. B., & Riedel, J. C. (2012). Evaluation of simulation games for teaching engineering and manufacturing. *Procedia Computer Science*, *15*, 210-220.

Hew, K. F., & Cheung, W. S. (2014). Students’ and instructors’ use of massive open online courses (MOOCs): Motivations and challenges. *Educational research review*, *12*, 45-58.

Hu, H., Ding, J., Zhang, S., Li, Y., Bai, L., & Yuan, N. (2013). Photodeposition of Ag 2 S on TiO 2 nanorod arrays for quantum dot-sensitized solar cells. *Nanoscale research letters*, *8*(1), 1-7.

J. van Zolingen, S., Streumer, J. N., De Jong, R., & R. van der Klink, M. (2000). Implementing on-the-job training: critical success factors. *International Journal of Training and Development*, *4*(3), 208-216.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 873086.

P. Karagiannis, T. Togias, G. Michalos, S. Makris, "Operators Training Using Simulation And VR Technology", 8th CIRP Global Web Conference (CIRPe 2020), Procedia CIRP, Volume 96, pg. 290-294 , 14-16 Oct, (2020)

Karnouskos, S. (2017). Massive open online courses (MOOCs) as an enabler for competent employees and innovation in industry. *Computers in Industry*, *91*, 1-10.

Kloosterman, H. J. (2019, June). Be Bold in Learning. In *81st EAGE Conference and Exhibition 2019* (Vol. 2019, No. 1, pp. 1-5). European Association of Geoscientists & Engineers.

Kobes, D. (2013). Making On-the-Job Training Work: Lessons from the Boeing Manufacturing On-the-Job Training Project. *Jobs For the Future*.

Mavrikios, D., Papakostas, N., Mourtzis, D., & Chryssolouris, G. (2013). On industrial learning and training for the factories of the future: a conceptual, cognitive and technology framework. *Journal of Intelligent Manufacturing*, *24*(3), 473-485.

D. Mavrikios, K. Georgoulias, G. Chryssolouris, "The Teaching Factory Network: A new collaborative paradigm for manufacturing education", 9th Conference on Learning Factories(CLF 2019), Procedia Manufacturing, Volume 31, pg. 398-403, 26-28 March, Braunschweig, Germany (2019)

Mayrhofer, W., Nixdorf, S., Fischer, C., Zigart, T., Schmidbauer, C., & Schlund, S. (2021). Learning Nuggets for Cobot Education: A Conceptual Framework, Implementation, and Evaluation of Adaptive Learning Content. *Implementation, and Evaluation of Adaptive Learning Content (June 17, 2021)*.

Nikolakis, N., Siaterlis, G., &Alexopoulos, K. (2020). A machine learning approach for improved shop-floor operator support using a two-level collaborative filtering and gamification features. *Procedia CIRP*, *93*, 455-460.

P. Stavropoulos, H. Bikas, D. Mourtzis, “Collaborative Machine Tool design: the Teaching Factory paradigm”, 8th Conference on Learning Factories, (CLF2018), 12-13 April, Patras, Greece, Vol. 23, pp. 123-128, (2018)

Pfeiffer, S. (2015). Effects of Industry 4.0 on vocational education and training. *Vienna: Institute of Technology Assessment*.

Pourabdollahian, B., Taisch, M., &Kerga, E. (2012). Serious games in manufacturing education: Evaluation of learners’ engagement. *Procedia Computer Science*, *15*, 256-265.

Rentzos, L., Doukas, M., Mavrikios, D., Mourtzis, D., & Chryssolouris, G. (2014). Integrating manufacturing education with industrial practice using teaching factory paradigm: A construction equipment application. *Procedia CiRP*, *17*, 189-194.

V. Siatras, L. Athanasopoulou, K. Alexopoulos, P. Stavropoulos, D. Mourtzis, "Applying the Teaching Factory Paradigm and Augmented Reality Technology for Operator Training in Assembly Operations", Proceedings of the 11th Conference on Learning Factories (CLF 2021), Available Online, 1-2 July, Graz, Austria (2021)

Solga, H., Protsch, P., Ebner, C., &Brzinsky-Fay, C. (2014). *The German vocational education and training system: Its institutional configuration, strengths, and challenges* (No. SP I 2014-502). WZB Discussion Paper.

S.R. Sorko, M. Brunnhofer, Potentials of Augmented Reality in Training, Procedia Manufacturing, Elsevier B.V., (2019) 85–90

Thelen, K. (2007). Contemporary challenges to the German vocational training system. *Regulation & Governance*, *1*(3), 247-260.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 873086.

UAW-Chrysler National Training Center. World Class ManufacturingAcademy. https://www.wcm.fcagroup.com/en-us/wcm_academy/Pages/default.aspx (accessed on 08/02/2022).

Vretakou, V., &Rousseas, P. (2003). *Vocational Education and Training in Greece: Short Description. CEDEFOP Panorama Series*. CEDEFOP, PO Box 22427, Thessaloniki, GR 55102 Greece.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 873086.