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Learning Factory-Based Training Scenario in Vocational Education and Training Center

Application to Future Assembly Line Operators of Industry 5.0

Ikram Ahidar[1,2] | Andreas Riel[1,2] | Michael Geis[3] | Joachim Metternich[3]

[1]Univ. Grenoble Alpes, CNRS, Grenoble INP, G-SCOP, Grenoble, France | [2]Grenoble INP Foundation, Grenoble, France | [3]Institute for Production Management, Technology and Machine Tools (PTW), TU Darmstadt, Darmstadt, Germany

Correspondence: Ikram Ahidar (Ikram.ahidar@grenoble-inp.fr)

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ABSTRACT

Industry 4.0 training has become a challenge. Many existing programmes are targeted at students and employees rather than at job seekers without prior industry experience. Vocational Education and Training (VET) centres are also a key element in the Industry 4.0 ecosystem, as they play an essential role in delivering training in this field. Learning by doing is a recognized pedagogical approach in training, and the Learning Factory (LF) can serve as a practical tool to support its implementation. How can we use LFs to deliver the skills needed for operators of the future? This study presents a pilot case on the design and implementation of a training scenario developed for future Assembly Line Operators using a LF in a VET centre. The training scenario incorporates various active learning methods, such as challenges. This training is specifically designed for people who have no prior industry experience. This pilot study indicated encouraging trends in knowledge acquisition related to Industry 5.0, while also offering preliminary insights for improving future training activities.

1 | Introduction

Industry 4.0 is characterized by the introduction of cyber-physical systems, data interconnectivity, and the adoption of industry technologies such as the Internet of Things (IoT), Digital Twins (DT), Artificial Intelligence (AI), additive manufacturing, and cybersecurity, among others (Bai et al. 2020; Wu et al. 2024). The term Industrie 4.0 emerged in Germany around 2011 as part of the German federal government's High-Tech Strategy and was officially presented at the Hannover Fair (Pfeiffer 2017). The concept aimed to promote digitalization and maintain the global competitiveness of German manufacturing industries. However, the initiative was not purely scientific in origin. It was developed through collaboration between government bodies, research institutions, and industrial actors, including major German corporations and employer organizations (Pfeiffer 2017; Fuchs 2018). The concept, therefore, served both technological and political objectives, particularly the mobilization of public funding and industrial support for digital transformation.

This paradigm shift has profoundly disrupted enterprise organizational structures with human, organizational, and environmental challenges (Obiso et al. 2019). Consequently, the European Commission has championed the emergence of Industry 5.0, which supplements future industry with three critical dimensions: human-centricity, environmental sustainability, and operational agility (European Commission 2021). In the literature, there are several definitions about this topic, but in the end, all of them are about these three pillars (Maddikunta et al. 2022).

Industry 5.0 is intended to transform manufacturing systems worldwide by relieving human workers of monotonous, hazardous, and repetitive tasks wherever feasible (Nahavandi 2019). Moreover, prioritizing workplace well-being by implementing programmes to support employees' mental and physical health, recognizing that their well-being is crucial for productivity and creativity.

One of the actions of the international chair Industry 4.h is the valorization of the human being in society in general and in the factory in particular, especially in terms of training. The majority of companies within the supply chain struggle to transition to Industry 4.0 due to a lack of necessary skills (Li 2024; Pech and Vaněček 2022). This transition must be accomplished with a focus on continuous training, both within private and public organizations, as well as externally through training centres and schools. The goal is to train people at all levels within a company. We have noticed that there is a significant emphasis on training engineers and technicians in Industry 5.0 disciplines, but it is often forgotten that in these so-called smart factories, there will always be a need for operators at the operational level, whether in maintenance, production, safety, or quality. Shop floor operators are the first to input data into the system, a foundational element of Industry 5.0. This data is later analyzed by engineers to drive decision-making and process optimization. The quality and reliability of the collected data are critical to the overall performance of the organization. Therefore, empowering operators through targeted training, based on clearly identified needs, provides a strategic advantage and enhances the value of data-driven operations (Streumer and Calon 1997). This approach ensures more accurate data collection and enhances collaboration between operators and engineers. How can we raise awareness among workers about transitioning to Industry 5.0 and correct the misconception that Industry 5.0 eliminates jobs rather than creating them? Through the activities of the chair, we aim to create simple, engaging training programmes targeting job seekers without prior industry experience.

Learning Factories (LFs) are real-world environments that replicate industry needs and can effectively operationalize the philosophy of learning by doing (Abele et al. 2017). Our article addresses the following research question:

RQ1: How can we use LFs to train people without an industrial background in Industry 5.0 in Vocational and Education Training (VET) centre?

Our objective is to develop a pilot study of "Learning Factory-based training" (LFBT) targeting people with no prior knowledge in industry in VET centre, enabling them to take their first steps toward becoming future Assembly Line Operators. This aims to support them in finding suitable job opportunities within the Industry 5.0 landscape. So, Industry 5.0 should not create more inequalities and more unemployment. This paper is organized as follows: The following section covers the methodology. The third section discusses related work from the literature. The fourth and fifth sections are dedicated to a case study on the implementation of LFBT with a French VET centre that provides practical training to prepare individuals for the job market. The conclusion and discussion will summarize and close the study.

2 | Methodology

This study adopts an experimental approach in the field of education, aiming to evaluate the effectiveness of a LFBT intervention. More specifically, it is designed as a pilot quasi-experimental study conducted in a VET context. The proposed training scenario was implemented with a group of participants without prior industrial background, and its impact was assessed through multiple dimensions, including knowledge acquisition, practical skills development, and learner perception. Such an approach is commonly used in educational research to evaluate innovative pedagogical methods in real-world learning environments, where fully controlled experimental conditions are often not feasible.

This study was designed as a pilot study aimed at evaluating the feasibility and initial effectiveness of the proposed LFBT approach. In line with established research practices, pilot studies are not intended to provide statistically generalizable results but rather to test innovative interventions, refine methodological procedures, and identify potential implementation challenges before larger-scale investigations (Thabane et al. 2010; Leon et al. 2011a). Consequently, they are typically conducted with relatively small sample sizes, reflecting their exploratory nature (Van Teijlingen and Hundley 2002a). This is particularly relevant in VET contexts, where access to participants is often constrained, and learning environments are practice-oriented. Therefore, the sample size adopted in this study is consistent with methodological standards for pilot research, while future work will focus on extending the study to a larger and more diverse population to enhance the generalizability of the findings.

Figure 1 illustrates the methodology we adopted to address our research question. The methodology is structured in two main phases: fieldwork and case study implementation.

The fieldwork phase involved close collaboration with VET centres, ensuring alignment between the proposed training approach and real industrial needs. In parallel, the training was situated within a LF environment, providing a realistic, industry-relevant setting that replicates production systems and workflows.

Building on this foundation, the case study phase focused on the design, deployment, and evaluation of a LFBTscenario tailored for future Assembly Line Operators with no prior industrial background. This phase consisted of three main steps. First, a scenario creation stage was conducted, during which training activities were designed based on Industry 5.0 requirements and aligned with targeted learning outcomes. Second, the scenario implementation stage involved delivering the training through hands-on activities, role-based tasks, and interactive challenges within the LF environment. Finally, the evaluation stage assessed the effectiveness of the training using multiple instruments, focusing on knowledge acquisition, practical skills development, and participants' perceptions.

This methodological approach enables the investigation of the feasibility and effectiveness of LFBT in supporting the integration of individuals without industrial backgrounds into Industry 5.0-oriented work environments.

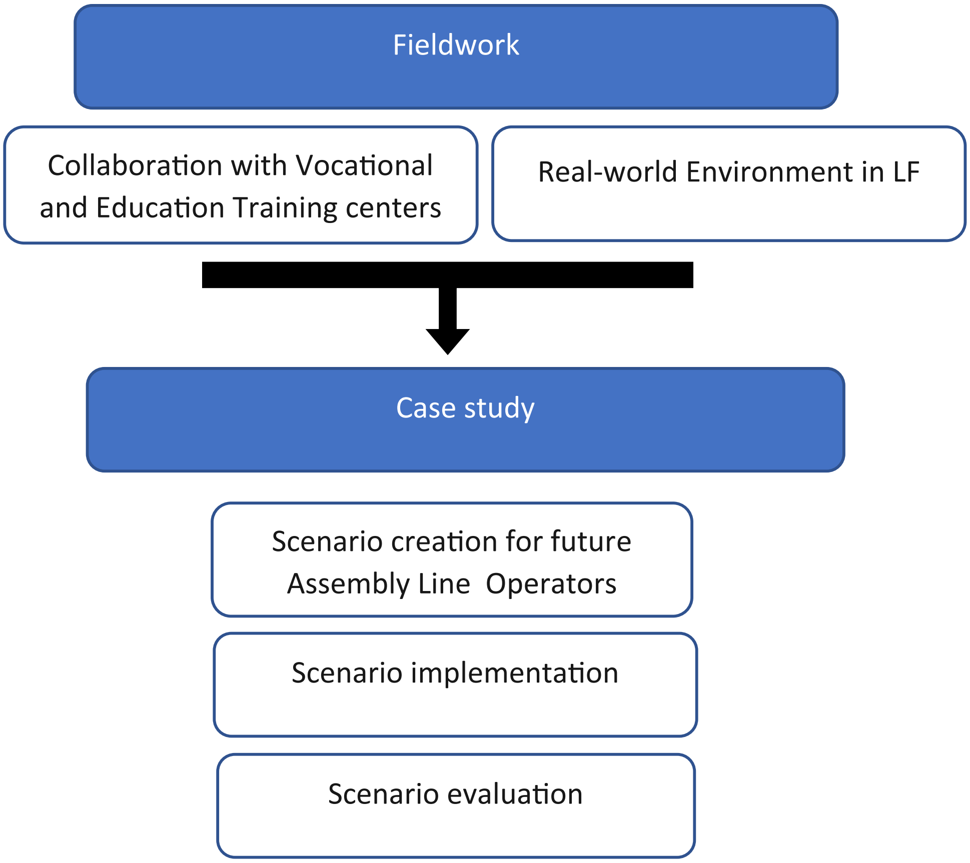


FIGURE 1 | Schematization of the methodology followed. [Color figure can be viewed at wileyonlinelibrary.com]

3 | Related Work

3.1 | Training Scenario and Existing Industry 4.0 and Industry 5.0 Training

First, we define what we mean by a scenario or training scenario. A scenario is a description of the steps, roles, activities, duration, and materials used in a learning setting. It is created by trainers, teachers, or pedagogical engineers to give structure to a learning experience, helping to organize learning effectively and improve knowledge transfer (Lamya et al. 2021; Riad et al. 2012).

The scenario must describe essential components such as activities, resources, tools, materials, and duration (Riad et al. 2012). The content of the scenario can vary depending on the target audience (Savard et al. 2020). A scenario serves as a guiding thread, but it is flexible and often adapted by the trainer during the training. This is to include some contents, remove or modify them (Bakki et al. 2020).

Regarding Industry 4.0 training, (Sala et al. 2023) developed a DT of a LF for a Bachelor of Computer Science programme over 5 months, utilizing AnyLogic software for simulation and Node-Red to create a customized dashboard. The project employed innovative methods, including hands-on learning, autonomous learning, and an interdisciplinary approach, as well as applying Bloom's Taxonomy (Anderson and Krathwohl 2001) within the Fischertechnik LF Industry 4.0. The paper outlines the steps of the training process (Martínez-Gutiérrez et al. 2023) developed a training scenario focused on DT and Virtual Reality (VR) for industrial operators. The goal of this training was to reduce errors and complete tasks as quickly as possible using tools like VR, computer applications, an industrial mobile robot, an industrial network, a web server, and a REST API. This paper provides a detailed description of the steps and the evaluation, including metrics such as the number of errors or failures, as well as participants' feedback on the methodology. As a result, training in real environments proved to be the most effective, followed by VR and then computer application training. This training took place in a laboratory of the School of Engineering at the University of León (Marmier et al. 2021) propose a general approach for employee training using a diagnostic tool to assess maturity levels (Belmonte et al. 2023) propose a university training programme for students in areas such as Data Science, Cloud Computing, Machine Learning, Deep Learning, Automation and Robotics, and DT. The study emphasizes low-cost, hands-on learning using technologies like smartphones, Android, LEGO kits, and open-source platforms to teach Logistics 4.0 concepts effectively (Roldán et al. 2019) developed a training programme for companies to facilitate knowledge transfer between experienced and new operators for complex assembly tasks, using technologies such as VR and process mining. The scenario was tested with several volunteers from the university, including ten students, PhD candidates, and one professor: thirteen men and seven women, aged 21 to 48 (Yang et al. 2018) developed an approach to train factory employees on new production management techniques. The training includes two phases: an online phase and a hands-on phase in a LF. Trainees are also evaluated on the training itself. The article focuses mainly on a general approach without going into the specifics of Industry 4.0 (Longo et al. 2017) designed an approach of training the operators in the workstation for the setup of a milling machine using Augmented Reality (AR) and intelligent tutoring systems to improve operator skills in Industry 4.0. This training is considered human-centric because it includes cognitive, ergonomic, and social factors. Evaluation showed improvement in setup times for operators trained with SOPHOS-MS compared to traditional methods. Key technologies include Unity 3D, Vuforia, and Lucene, targeting plant operators needing support for complex tasks (Gualtieri et al. 2024) has also used AR and Visual management to train industrial operators in setting up a machine using the Microsoft HoloLens 2 Head-Mounted Display HMD. Improvements are also seen in the task performance of the operators (Pérez et al. 2019) had made training for industrial operators on their roles to interact with Robots, using VR by modelling the robot through DT. This methodology had improved operator capabilities through safe training.

In conclusion, these studies have described the structure of training related to Industry 4.0. However, all of these papers focus only on employees, operators, managers, or students with prior knowledge, and do not target people without a background, which is fundamental for an inclusive Industry 5.0. Moreover, the training generally focuses on a single or two Industry 5.0 technologies, whereas in reality, people in Industry 5.0 interact with multiple technologies simultaneously. These trainings were also not described according to a structured programme linking skills to learning outcomes, nor did they provide detailed descriptions of the activities.

3.2 | Teaching/Learning Factory

A Learning Factory is described as a learning environment similar to a real factory, with processes, machines, and products, and also technologies matching the real industrial standards (Scheid 2018; Roll and Ifenthaler 2021; Schallock et al. 2018; Assoc. Prof., Economic Education Department of STKIP PGRI Jombang, East Java Indonesia, agustkip@gmail.com, Prianto A, Winardi W, Assoc. Prof., Civic Education Department of STKIP PGRI Jombang, East Java Indonesia, win.stkipjb@gmail.com, Qomariyah UN, Mathematic Education Department of STKIP PGRI Jombang, East Java Indonesia, umi.stkipjb.gmail.com 2021).

Teaching and Learning Factories are based on the same concept but follow different approaches: the Teaching Factory transfers real industrial problems from companies to students for analysis, while the LF allows learners to experiment in a simulated industrial environment and later validate their results in real industry settings (Mourtzis et al. 2018; Stavropoulos et al. 2018). It is a new synergy collaboration model between industry and academia to address real market needs and shop floor problems (factory to classroom), but also to train industrial workers and operators and to validate some new concepts in industry (lab to factory) (Mavrikios et al. 2018).

LF enables an active learning approach to training that closely reflects real job market conditions. It is part of a "learning by doing" philosophy. LF is used in engineering schools using Project-Based Learning, for example (Chelini and Richert 2023), but also in vocational high schools, where learners are better prepared to integrate into the workforce (Assoc. Prof., Economic Education Department of STKIP PGRI Jombang, East Java Indonesia, agustkip@gmail. com, Prianto A, Winardi W, Assoc. Prof., Civic Education Department of STKIP PGRI Jombang, East Java Indonesia, win. stkipjb@gmail. com, Qomariyah UN, Mathematic Education Department of STKIP PGRI Jombang, East Java Indonesia, umi. stkipjb. gmail. com 2021). Industry 4.0 LF offers significant advantages for Small and Medium-sized Enterprises (SMEs) by providing a low-risk environment to experiment with emerging technologies and supporting their effective integration into operational production systems (Mourtzis et al. 2018). It also offers a training environment that supports Industry 4.0 transformation projects, especially for workers, when post-training coaching is provided at their home plants (Schallock et al. 2018).

LF can provide a demonstration of Industry 4.0, which is usually the standard practice, but it is recommended to allow learners to engage in hands-on learning, as it is more effective than simple demonstrations and enables them to truly benefit from these learning activities (Elbestawi et al. 2018; Simons et al. 2017). Allowing industrial learners to experience the new shop floor in a smart LF is also an opportunity to understand the real problems faced by workers. It helps them evaluate the new workstations and address the question of human conditions in Industry 4.0. This immersive experience can then lead to a real project involving actual users of the machines and shop floor environment (Reuter et al. 2017). LFs can be used online, on-site, or in a hybrid format (Mourtzis et al. 2023).

The studies of the effectiveness of LFs in VET centres are scarce compared to universities and engineering schools (Roll and Ifenthaler 2021). Particularly, we did not find any article in the literature targeting job seekers or people in VET centres without an industrial background.

To compensate for this lack, we will propose in the next section the Industry 5.0 LFBT scenario that we propose targeting people without prior knowledge in Industry 5.0 in a VET centre for the occupation of future Assembly Line Operators.

3.3 | VET Centres

VET refers to learning aimed at specific jobs and technical skills, and it has become a central policy tool for tackling youth unemployment, skills shortages, and economic development. VET systems depend on each country's history, institutions, and labour market, which makes it difficult to apply the same model everywhere (Gonon and Deissinger 2021; Eichhorst et al. 2015; Mayer 2001; Clarke et al. 2021).

Comparative work identifies several types of VET systems, including school-based vocational and technical schools, firm-based apprenticeships, and dual systems that combine school and workplace learning (Keep 2012). Countries cluster into vocational-oriented systems with strong work-school combinations (e.g., Germany, Switzerland, Austria), highly vocational but mainly school-based systems (e.g., Czech Republic, Slovakia), and general-education-oriented countries with smaller VET sectors (Eichhorst et al. 2015; Salas-Velasco 2024). VET centres often operate in close collaboration with companies, employers, and social partners in order to ensure that training programmes reflect current technological developments and labour-market demands. Such collaboration may include apprenticeships, internships, and workplace-based learning, allowing learners to gain experience in authentic work environments and improving their employability after graduation (OECD 2025a).

Furthermore, VET centres support lifelong learning by offering flexible learning pathways for diverse target groups, including young students in initial vocational education, adults seeking to reskill or upskill, and job seekers aiming to improve their employment prospects. As labour markets evolve due to digitalization and the green transition, VET institutions play an increasingly important role in developing adaptable technical competencies and transferable skills required for future occupations (OECD 2025b).

For the purpose of this paper, the term VET centre refers specifically to institutionalized training organizations that provide structured vocational education programmes and dedicated training infrastructure. Vocational education is typically delivered through recognized institutions that offer organized learning environments and systematic training leading to labour-market relevant competencies (OECD 2025a).

4 | Use Case Training Scenario Design and Implementation

4.1 | Participants and Selection of Cases

This study involved nine participants who took part in a training programme of 23 days. All participants included were individuals enroled in a professional conversion pathway that aimed to make their transition into the industrial sector. Their inclusion was therefore determined by their active engagement in a reemployment process within the industry, and by their need to acquire vocational skills enabling them to get a job in the industry sector. The participants in this pilot training programme present a diverse profile in terms of gender, age, experience, and education. The group consists of five women and four men, reflecting a balanced gender representation. In terms of age, two participants are in their fifties (one woman and one man), while the remaining trainees are in their twenties or thirties. None of the participants has prior industry experience, highlighting the importance of this training in supporting their transition into the sector. Educational backgrounds are varied: one participant holds a Brevet de Technicien Supérieur BTS (European Qualifications Framework EQF level 5), three have completed high school (baccalaureate, EQF level 4), and the others either possess a Certificat d'Aptitude Professionnelle CAP certification (EQF level 3) or have no formal qualifications (EQF level 1). This diversity reflects varied career paths, with previous work experience in housekeeping, butchery, cashier roles, snack preparation, and warehouse operations.

4.2 | Training Instrument Design

Our approach is based on the learning by doing, where we have chosen the LF because it gives several advantages to trainees.

4.2.1 | Description of the LF of the VET Centre

The VET centre hosts a LF, a cyber-physical platform designed for education and research. It replicates connected production technologies using a modular smart factory system. Il is an Assembly Line for producing didactic cell phones. The line features a manual workstation, a cobot workstation for Printed Circuit Board PCB mounting and adding electrical fuses, a warehouse, and a machining line (pressing, drilling, and so on) (Marcon et al. 2022). Materials and products are transported between modules via belt conveyors with carriers or boxes between production workstations. The product is also transported by autonomous mobile robots. Each carrier or box is equipped with a Radio Frequency Identification (RFID) tag that stores data identifying the item and its load. A carrier can transport one pallet holding a product, such as a front cover, along the endless conveyor belt. Four workstations are equipped by AR.

4.2.2 | Workshops

We conducted regular workshops with the trainers to understand the needs of the VET Centre and to gain a comprehensive understanding of their pathways and training offerings. We chose one programme that targets job seekers aspiring to be recruited by industrial companies as production or Assembly Line Operators. Two days will be dedicated to Industry 5.0 training. The future Assembly Line Operators will need to acquire skills in monitoring processes, machines, products, and robots, as well as in using software systems such as Manufacturing Execution System (MES). They don't need advanced technology training like engineers and designers (Chelini and Richert 2023). The workshops with the trainers were held regularly over 3 months, twice a month.

Figure 2 shows the approach we followed to deliver the Industry 5.0 LFBT scenario.

4.2.3 | Learning Outcomes Identification

The Learning Outcomes for the trainees were described based on the competencies and skills they need to acquire to work in the Industry 5.0 era. Together with the trainers, we used various sources and frameworks (Figure 3) to define the Learning Outcomes (Table 1).

First of all, the training of the present study was planned as a 2-day session, which was a very important criterion to set realistic and achievable objectives within the given duration. Additionally, we consulted their main training programme to align the content with other subjects they had already seen.

Learning Outcomes in Table 1 are extracted from the ESCO framework (European Skills, Competences, Qualifications, and Occupations). We chose ESCO (version 1.2.0) because it is designed to align with Industry 5.0 technological advancements and supports policymakers by providing up-to-date labour

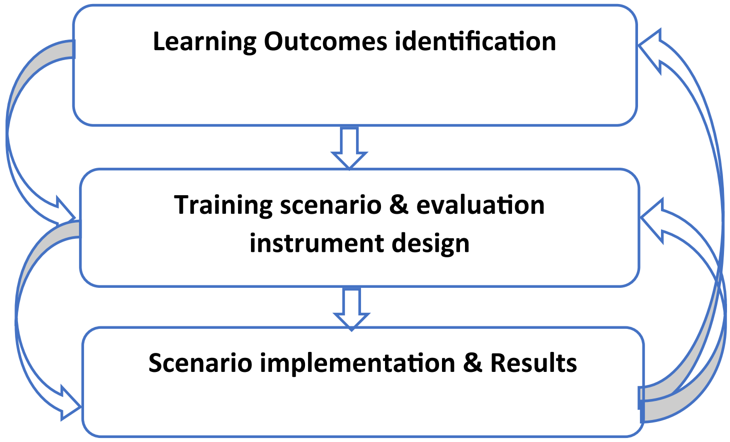


FIGURE 2 | The main steps of the approach followed. [Color figure can be viewed at wileyonlinelibrary.com]

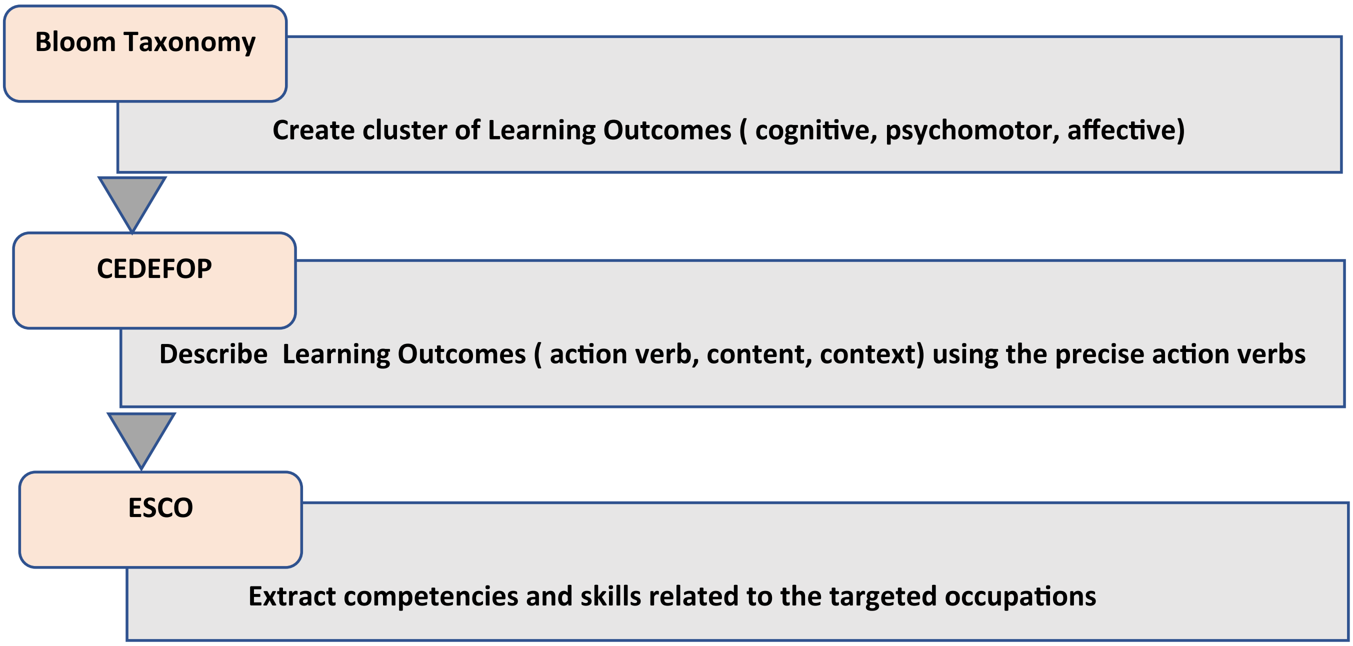


FIGURE 3 | Steps and frameworks used for describing Learning Outcomes. [Color figure can be viewed at wileyonlinelibrary.com]

market intelligence (Chiarello et al. 2021). We did not find exactly the occupation we were looking for, for this group, but we chose the closest one. « 3139.1 Automated Assembly Line Operator» and «3139.2 Industrial Robots Operator». We have identified knowledge related to manufacturing processes within the ESCO framework, but we have also incorporated Industry 5.0-specific knowledge that learners must acquire by the end of the training. For the hard and soft skills, some were inspired by ESCO's essential and optional skills. For example, (HS3) in Table 1 is inspired by the optional skill « supply machines » from the occupation «3139.1 Automated Assembly Line Operator» was considered. However, other frameworks, such as the O*NET Occupational Information Network for Team Assemblers (51-2092.00), are also available. The selection of a framework depends on the specific needs, context, and location of the training centre.

Based on the competences and skills of ESCO but also on the real needs of trainers and on the requirements of the Industry 5.0, we have set the Learning Outcomes using the levels of Bloom's taxonomy, cognitive, psychomotor and affective (Anderson and Krathwohl 2001; Bhargav et al. 2016; Ullah et al. 2020). To describe these Learning Outcomes, the guide of the European Centre for the Development of Vocational Training (CEDEFOP) (European Centre for the Development of Vocational Training 2017) has been consulted and followed. In VET centres, Learning Outcomes are particularly important because they provide the skills that enable learners to be ready to work, and also promote lifelong learning (European Centre for the Development of Vocational Training 2024). In general, they are based on the action verb, the content, and the context. We have also integrated soft skills because, in the context of Industry 5.0, soft skills are indeed highly demanded by employers. These skills are divided into intrapersonal skills (the human with themselves) and interpersonal skills (the human with others, where social interaction plays a key role) (Poláková et al. 2023).

TABLE 1 | Learning outcomes for future assembly line operators.

Ref	Knowledge (cognitive)	Ref	Hard skills (psychomotor)	Ref	Soft skills (affective)
K1	Identify and describe key Industry 5.0 technologies and their use case in an Assembly Line 5.0.	HS1	Initiate or setup the Operational technology (e.g. cobots, machine, conveyor.) in an Assembly Line 5.0.	SK1	Solve hardware and software problems in the Assembly Line 5.0.
K2	Explain the principles of production management systems (e.g., MES) in Assembly Line 5.0.	HS2	Activate and manage the robot programmes via the HMI in the Assembly Line 5.0.	SK2	Communicate and collaborate with colleagues across the organization.
K3	Analyze the organization of production process in an Assembly Line 5.0.	HS3	Prepare and restock raw material inventory in the warehouse of the Assembly Line 5.0.	SK3	Collaborate with machines or/and cobots in the Assembly Line 5.0.
K4	Interpret the meaning of specific pictograms (especially those related to safety).	HS4	Launch work orders (OF) using MES for the Assembly Line 5.0.	SK4	Value vigilance and awareness regarding safety protocols across the organization.
K5	Interpret the advantages and challenges of Industry 5.0 for humans.	HS5	Monitor production/assembly processes (cobots, machines and conveyor belt) using HMI in the Assembly Line 5.0. • Identify critical control points and areas of concern • Diagnose potential malfunctions	SK5	Adapt and be flexible for new situations, new events in the organization and new technologies (if applicable).
		HS6	Collaborate with a cobot on a shared workstation and handle it effectively.		
		HS7	Use augmented reality to access to technical resources (e.g., via a tablet).		
		HS8	Navigate and train in a virtual environment (VR) to practice on a workstation.		
		HS9	Inspect quality product and interpret the rejection of parts by camera inspection and correct the defect		

4.2.4 | *The Design of a Pedagogical Training Scenario*

We chose to create a training scenario to clearly outline the progression of activities and Learning Outcomes. Table 2 presents the scenario designed to cover the tasks the learners will perform as Assembly Line Operators in the context of Industry 5.0. This scenario was developed in collaboration with the VET trainers.

As the word count is limited, we did not have enough space to explain in detail the content of the challenges; we only explained, in the next section, the design of the evaluation instrument related to these challenges (Tables 3 and 4) and the results obtained (Table 4 and Figure 7).

4.3 | Evaluation Instrument Design

The evaluation approach that we have followed is inspired by a mix of validated frameworks from the literature, like Miller's Pyramid (Miller 1990) and the Kirkpatrick Evaluation model (Smidt et al. 2009; De S. Bergamo et al. 2022). We have chosen these models because they provide a structured approach to assess Learning Outcomes within multiple dimensions. It combines three complementary instruments: a knowledge questionnaire assessing theoretical understanding, challenges targeting operational know-how, and some selected soft skills evaluated using Behaviourally Anchored Rating Scales (BARS), and the third one in an anonymous questionnaire measuring learners' perceptions of the training approach. The questions were constructed and reviewed by the experts some of whom are the authors of this study and also the trainers of the VET centre, following Content Validity Index (CVI) recommendations (Polit and Beck 2006), ensuring relevance, clarity, and alignment with training objectives.

4.3.1 | *Knowledge and Know How Assessment Instrument Design*

The knowledge assessment is related to the cognitive domain of learning, consistent with the "Knows" and "Knows How" levels of Miller's Pyramid, but also "Learning" and "Behaviour" levels of Kirkpatrick's evaluation framework (Smidt et al. 2009; De S. Bergamo et al. 2022).

It objectively evaluates the trainees' understanding and retention of core concepts covered during the training. For the "knows" assessment, it is a structured questionnaire including open-ended questions targeting conceptual understanding and analytical reasoning. The questions focus on the main dimensions of *Industry 5.0*, including key technologies, human–machine interaction, mixed reality applications, and industrial information systems. For the "know how" assessment, the challenges mentioned in Table 2 represent a practice exercise that lets the participants set up the Assembly Line and the cobots, search for a drawing using AR, and prepare a production order using MES. The evaluation of these challenges follows the principles of BARS in Table 3. The evaluation framework consisted of ten criteria, each scored on a five-point scale (1–5). Challenges 1 and 2 were assessed using only three criteria (task conformity, task duration, and safety), resulting in a maximum score of 15 points for each challenge. In contrast, Challenge 3 was evaluated using all ten criteria, resulting in a maximum score of 50 points. Ratings were measured on observable behavioural indicators to avoid subjective impressions.

4.3.2 | *Perception Assessment Instrument Design*

This evaluation corresponds to the "Reaction" level of the Kirkpatrick model, and complements the knowledge assessment by collecting participants' perceptions.

This evaluation lets us collect subjective experience with the learning approach and training environment. A questionnaire combining 8 questions: Closed-ended to quantify attitudes and perceived effectiveness, and open-ended questions to collect detailed and qualitative feedback. Responses are collected anonymously to promote honest feedback. The assessment includes perceived clarity of content, enjoyment, engagement, applicability to professional context, transfer of knowledge, and also insights to improve future trainings.

5 | Training Implementation and Results of the Evaluation

5.1 | Training Implementation

Based on Table 2, on the first day, the session began with a VR experience in a mountain villa and in an Industry 5.0 factory. Each participant tested both virtual environments to break the ice and to experience the immersion. They then attended demonstrations of automated technologies in the LF, including the various workstations, mobile robots, and cobots.

In the afternoon, participants attended a presentation using a video projector, in round-table discussions aimed at delivering the knowledge. At the end of the first day, they carried out Challenge 1, which consisted of identifying the technologies available in the LF and explaining their applications or use cases in production.

The second day was dedicated to the two challenges. The first involved using AR to locate schematics in two different workstations, offering participants two opportunities to search for the required diagram. The final challenge consisted of fulfilling a simulated customer order through a role-based game activity, where each team had to assign production roles and manufacture the product ordered by the customer.

Each challenge emphasized teamwork, problem-solving, and the application of Industry 5.0 technologies, with scoring based on technical accuracy, completion time, safety compliance, and collaboration.

5.2 | Results of the Evaluation: Data Processing and Analysis

Before making the analysis, all data collected has been cleaned. Responses were reviewed for completeness and internal coherence, and datasets were harmonized to ensure complementarity across the three assessments. Out of the total sample ($n = 9$), nine valid responses were obtained for the anonymous

TABLE 2 | The LFBT scenario instrument created for the two-day training.

Duration	Training steps	Activity	Approach	Materials	Learning outcomes	Evaluation
2 h	Step1 Capture students' interest and actively engage them in their initial exploration of key Industry 5.0 technologies	Activity1/1 Immersion in two virtual worlds	Immersion through VR Ice breaker	2 VR Head sets	—	—
		Activity1/2 Discovery of a Cobot/Robot in action	LF	Robots/Cobots	—	—
4 h	Step2 Transmit the essential knowledge to retain for Industry 5.0	Activity2/1 The industrial revolutions	Visual and audio content Multimodal learning approach	Videos	K1	Knowledge assessment
		Activity2/2 The perception of Industry 4.0 by individuals and businesses	Roundtable discussion about testimonials from industry professionals	Videos	K5	Knowledge assessment
		Activity2/3 The benefits of Industry4.0 for humans and their roles in Industry 4.0	Contrast and Comparison images for stimulating creativity and reflection	Images	K5	Knowledge assessment
		Activity2/4 The enabling technologies of Industry 4.0 and their use case	Visual and audio content Multimodal learning approach	Videos	K1	Knowledge assessments & Challenges
		Activity2/5 Industry 5.0	Contrast and Comparison images for stimulating creativity and reflection	Images	K5	Knowledge assessment
1 h	Step3 Let the trainees apply their knowledge in a real-world environment	Activity3.1 Challenge 1 Recognize the tech!	LF	Cobot Product pallet VR glasses AR tablet MES computers AMR Energy box Digital twins	K1	Challenge (Table 3)
1, 5 h		Activity3.2 Challenge 2 AR Explorer Mission!	Challenge Real environment: LF	AR tablet QR box Assembly Line	HS7 SK1-SK5 K4	Challenge (Table 3)

(Continues)

TABLE 2 | (Continued)

Duration	Training steps	Activity	Approach	Materials	Learning outcomes	Evaluation
4 h		Activity3.3 Challenge 3 Customer Order challenge!	Challenge Role based-game Real environment: LF	Cobot Assembly Line Robot MES supervision station	HS1-HS6 HS9 SK1-SK5 K2-K4	Challenge (Table 3)
1, 5 h	Step4 Stimulate reflection on learning	Discussion, Debriefing and Assessment	Reflection questions	—	—	—

perception test, while only seven participants returned the knowledge evaluation test. The know-how observation challenges were done to the nine participants. The difference in response rates was expected, as anonymity facilitated participation, whereas nominative assessments required explicit identification. Quantitative data from the knowledge tests and know-how evaluations were coded numerically. Qualitative data from the open-ended items and interviews were processed by consolidating similar ideas into recurrent categories, allowing the extraction of patterns that complemented the quantitative findings.

Given the small number of participants ($n = 9$), applying complex statistical procedures to analyze the data doesn't seem appropriate. This allows the analysis to remain rigorous to simply reflect the real trends. Visual representations were produced to synthesize the results. These processes ensured a transparent and methodologically sound analysis of the empirical data that is aligned with the methodological requirements of small sample pilot studies.

Based on the results of the knowledge "knows" assessment (Figure 4), the responses to questions regarding the difference between AR, MR, and VR were correctly explained by almost all participants, indicating a strong understanding of these foundational concepts covered during the training. Similarly, questions addressing the advantages of Industry 5.0 on business and the positive impacts of Industry 5.0 on humans were correctly answered by the majority of participants, reflecting a solid grasp of the strategic benefits of these technologies.

In contrast, knowledge of specific industrial technologies and their practical applications was more variable. Only two participants were able to correctly identify both the technologies and their respective applications. Two additional participants identified the technologies but were unable to specify their applications, while two participants provided incorrect or incomplete responses. This variability suggests that focus needs to be given to know the technologies and how they are applied, such as the serious game dedicated to technologies and use cases (Ahidar et al. 2026).

The functions of MES were correctly identified by five participants, showing a moderate level of familiarity with production management tools, especially after the third challenge, because almost all tasks were based on MES.

Regarding the three dimensions of Industry 5.0, full recognition was limited: only three participants identified all three dimensions (human, environment, and resilience), while four participants identified them only partially, typically recognizing one or two dimensions. This result indicates that concepts related to Industry 5.0 remain partially assimilated, due to the focus of the training on the human dimension. Special activities related to resilience will be created for future scenarios.

The assessment results were analyzed to examine differences in individual performance as well as the influence of collaborative behaviour during the third challenge. Total scores were computed by summing the results from the three challenges. The evaluation criteria were based on the BARS explained before in Table 3.

TABLE 3 | BARS for challenges.

Criterion	1 Inadequate	2 Weak	3 Acceptable	4 Good	5 Excellent
Resource Allocation	Resources misallocated or unused.	Resources used inconsistently.	Adequate allocation with small inefficiencies.	Resources well assigned and coordinated.	Optimal use of resources with strategic foresight.
Stock Management	Stock errors frequent like Lack of raw material.	Occasional stock inaccuracies.	Generally correct stock handling.	Accurate and efficient stock tracking.	Proactive stock management anticipating needs.
System Start-up (Machines/Robots/ cobots)	Fails to start systems correctly.	Requires assistance to start systems.	Starts systems with minor errors.	Starts all systems properly.	Starts systems efficiently and autonomously.
Order Launching (MES)	Fails to launch orders correctly.	Launches orders with supervision.	Launches correctly with minor support.	Launches autonomously and correctly.	Launches autonomously and optimizes sequence.
Problem Solving and Breakdown Response	Unable to identify issues.	Identifies but poorly resolves problems.	Resolves standard issues with guidance.	Resolves issues independently.	Resolves complex problems proactively.
Safety and Ergonomics	Disregards safety protocols.	Applies safety inconsistently.	Generally safe and ergonomic.	Fully respects safety and ergonomics.	Models exemplary safety behaviour.
Use of Human Machine Interfaces	Fails to use interfaces.	Require assistance to use Interfaces.	Use interfaces with small errors.	Use interfaces without errors.	Propose ideas to improve interfaces.
Task conformity Quantity and quality of the output	Output with more than three defects	Output with three errors	Output with two errors	Output with only one error	Output meet the requirements
Duration	Significantly longer than expected (> 150%).	Exceeds expected duration by 25%–50%.	Completes task within ±20% of standard time.	Slightly faster than expected (−10%).	Performs efficiently; smooth and fast execution (-20% or more) without quality loss.
Team Cohesion& communication	No collaboration evident.	Limited collaboration.	Functional teamwork.	Effective collaboration and communication.	Highly synergistic and supportive teamwork.

TABLE 4 | Results of the challenges based on BARS framework.

	Challenge 1 Max 15	Challenge 2 Max 15	Challenge 3 Max 50
P1	10	12	Group 1 28
P2	9	9	
P3	10	12	
P4	9	7	
P5	10	10	Group 2 20
P6	12	12	
P7	10	12	
P8	12	12	
P9	10	12	

Figure 5 illustrates the distribution of total scores among participants based on Table 4, where every challenge was scored. The first and second challenges were based on three criteria of Table 3 (task conformity, duration, and safety). The maximum achievable score is 15 points for each challenge. The third challenge was based on the 10 criteria. The maximum achievable score is 50 points The analysis reveals that total participant scores ranged from 40 to 50 points, with an overall mean of 44.1. The highest performance was achieved by participants P1 and P3 (50 points), whereas the lowest score was obtained by P5 (40 points). Regarding Table 4, for challenge 2, P4 has the lowest score because she is the woman in her fifties who has difficulty using screens, and she also mentioned this in the perception assessment.

Regarding Challenge 3, this activity is not carried out individually but rather in groups, as it also aims to assess several soft skills, such as communication and teamwork. Two groups were formed because the LF includes two similar production lines. No specific selection criteria were used to create the subgroups; participants spontaneously divided themselves into two groups. A comparison between the two groups regarding the third challenge revealed that Group 1 achieved an average group score of 28, significantly higher than Group 2, which obtained an average of 20. This difference is explained by the variation in two criteria, communication and resource allocation, as well as safety and security. In fact, Group 1 quickly identified a group leader, who effectively allocated resources to each task related to production management and ensured clear communication between team and also regarding all identified issues.

In general, if you consider that the maximum total of the scales is 80, the scores obtained are higher than the mean. The difference between participants is not really significant.

Regarding the trainees' perceptions, this evaluation was conducted anonymously to ensure that their responses reflected their real impressions of the approach. Figures 6 and 7 represent the results of the perception of assessment. Challenge 3 was rated as moderately enjoyable by the majority of participants (5 participants), while 2 participants rated it as extremely enjoyable and 2 others as very fun. Challenge 1 and Challenge 2 were considered less enjoyable, but the difference between the three challenges was minor. All challenges were generally perceived as moderately easy to understand and perform. Only one participant reported that Challenge 3 was difficult. Concerning knowledge improvement, Challenge 3 was identified by most participants as the activity that most facilitated knowledge transfer, followed by Challenge 2 and then Challenge 1. Again, the differences among the challenges were relatively small.

Participants appreciated the hands-on activities with machines, as well as the exciting challenges that allowed them to discover new technologies and to experience the job of the future. They valued that the LF provided a practical learning experience. The interactive and engaging nature of the challenges kept them motivated. Participants appreciated the practical learning environment that enabled them to quickly learn new concepts that were considered complex before.

The most appreciated challenge was Challenge 3, which received 5 votes. Participants found it engaging and valuable. Challenge 2 also received positive feedback, with three votes, while one person did not respond. On the other hand, four participants mentioned that none of the challenges were the least appreciated. Challenge 3 followed, as it was considered too long and required a lot of movement, receiving three votes. Challenge 2 was noted to be difficult due to AR tablet handling, according to one vote. Challenge 1 was described as not interesting by one participant. However, four participants had no specific complaints about any of the challenges.

To make future sessions even more impactful, a few improvements were suggested: enhancing the interactivity of the second part of Table 2 based on Videos and Images, offering clearer explanations of the challenges, allocating more time for activities, and maintaining a balanced planning between speed and learning. Participants highlighted that the LFBT significantly helped them develop essential skills, provided a deep understanding of Industry 5.0 concepts, and gave them insight into the future shop floor operators.

6 | Limits of the Study and Future Research

This pilot study presents preliminary findings from the implementation of LFBT, designed to give a real experience and immersion in the future job roles as Assembly Line Ooperators. The participants of this training scenario are job seekers in a VET centre with no prior experience in industry. However, several limitations must be mentioned. The sample size, only nine participants, does not provide a sufficient basis for generalizing findings. The sample size was constrained by the availability of participants within the target, as the training was implemented in a specific organizational context with limited access to comparable groups to make a comparative analysis of other training approaches. The difference in qualifications and background in the VET centre let also makes it difficult to have a control group with the same conditions to make comparisons between the two approaches. Since our partner collaborates directly with organizations, like employment agencies, a participant group was assigned to us through this partnership. For this reason, we are currently developing more collaborations with multiple VET centres to gather broader and more diverse feedback, and they will be the subject of future publications.

Another limitation, we are not sure that the observed motivation will have a medium or long-term impact on participants' work practices and behaviour at their future real workstations.

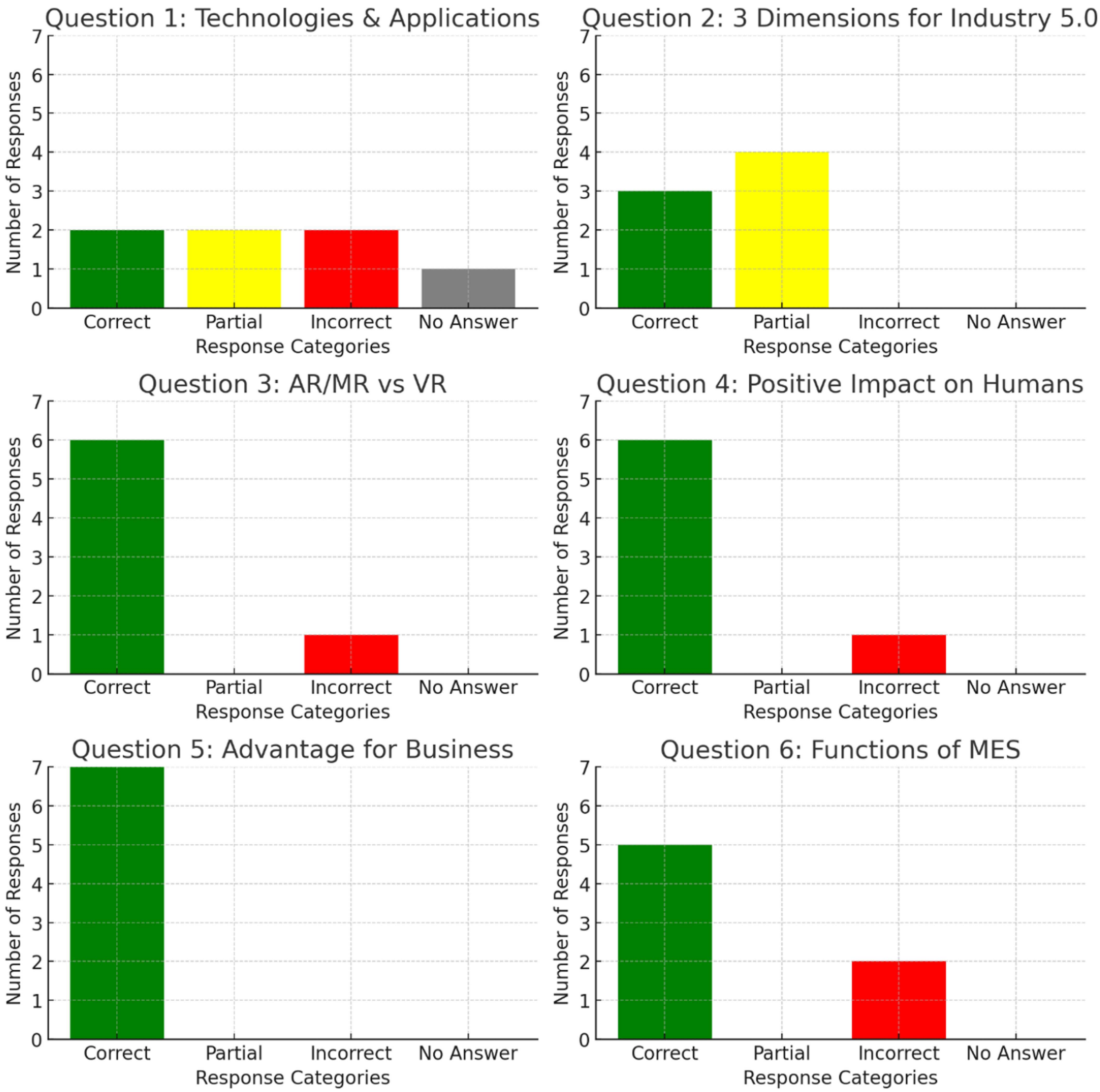


FIGURE 4 | Trainee responses to knowledge "knows" assessment. [Color figure can be viewed at wileyonlinelibrary.com]

Future work can include a longitudinal evaluation to assess the persistence of skills in the real workstations. We also need additional implementation in diverse VET centres to enhance the validity of our findings. A detailed analysis of implementation challenges across various organizational contexts, including lessons learned and failures identified during both the implementation process and design process, will also be conducted to support continuous improvement of the LFBT.

7 | Conclusion and Discussion

After demonstrating this experience and obtaining positive evaluation results through assessments with three instruments, we evaluated knowledge acquisition, practical skills, and trainees' perceptions of the LFBT dedicated to this target group of job seekers attempting to integrate into the Industry 5.0 labour market. Small-scale pilot experiments are widely recognized in training and development research as a valid means of identifying potential effects, refining training instruments, and informing the design of larger-scale studies (Abele et al. 2017; Thabane et al. 2010).

If we consider the perspective of inclusive Industry 5.0, job seekers should find opportunities within the Industry 5.0 environment, and VET centres play a crucial role as a link between this population and the needs of Industry 5.0 to deliver Industry 5.0 training.

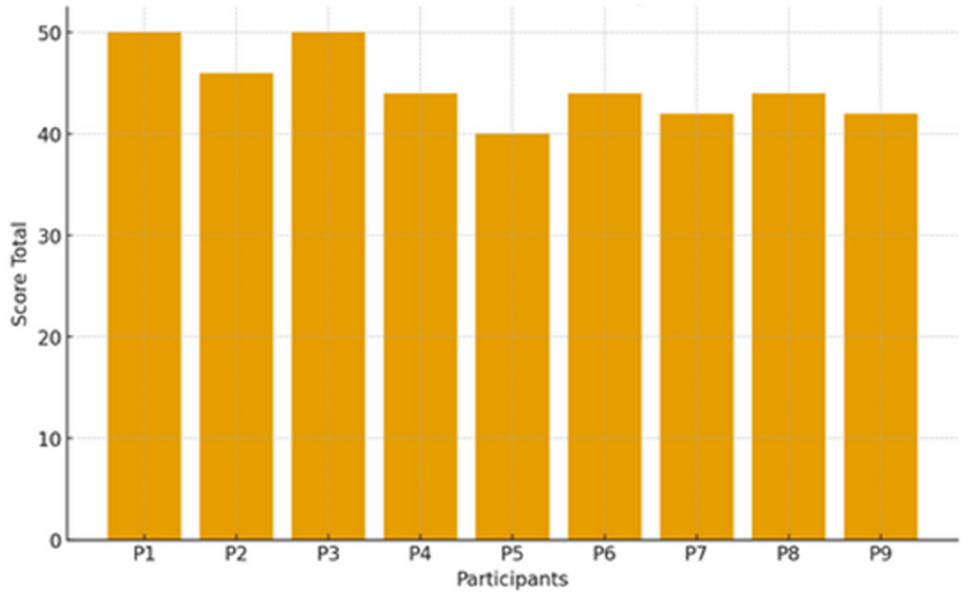


FIGURE 5 | Trainees response to "know-how" BARS assessment. [Color figure can be viewed at wileyonlinelibrary.com]

LFs can provide a realistic training environment and allow participants to explore Industry 5.0, especially since most of them have no prior industrial background or work experience. This type of training can therefore be the most appropriate approach, as it closely matches real factory settings. The detailed design of the LFBT is the answer to our research question. This environment enables us to assess whether job seekers without prior industrial experience can effectively perform as operators in an Industry 5.0 production line. This pilot study also provides insights into how LFs can be used to train individuals through a variety of activities, challenges, and role-based exercises, offering a practical, immersive learning experience.

We have demonstrated how we can effectively utilize LFs to transfer knowledge and structure training on topics related to Industry 5.0, especially with a hand on activities not only demonstration as recommended in literature (Simons et al. 2017; Erol et al. 2016). The effectiveness of LFs was already demonstrated in literature but for engineering students (Louw and Deacon 2020), for vocational students who are workers at the same time (Roll and Ifenthaler 2021) and for industrial workers (Reuter et al. 2017). By using the LFBT scenario, we were able to link all activities to specific Learning Outcomes. We observed that the active pedagogical approach is highly appreciated in training sessions, as it engages trainees and allows them to explore and understand the topics more deeply. LFs represent a valuable opportunity that should be fully leveraged, not only in higher education but also in VET centres.

Although this pilot study was conducted within the specific context of a French VET centre, the proposed LFBT approach has potential relevance beyond the national setting. VET systems exist in many countries and play a comparable role in preparing individuals for technical occupations and facilitating workforce integration (OECD 2025a). As the transition toward Industry 5.0 affects manufacturing sectors worldwide, the need to train future operators, including individuals without prior industrial experience, is a shared challenge across different countries. The pedagogical principles, for example learning by doing in a LF, are not limited to a single educational system and could therefore be adapted to other VET ecosystems. However, successful transfer would require consideration of country-specific factors such as institutional structures of VET systems, collaboration with industry partners, and regional labour-market needs.

Several challenges were encountered throughout the training, both at the design stage and during implementation. A major difficulty concerned the heterogeneity of participants in terms of age, educational background, origin, and cultural diversity. This issue has likewise been reported in previous studies (Ullah et al. 2020; European Centre for the Development of Vocational Training 2017). Participants with limited formal education or with difficulties in oral or written communication were provided with additional guidance and support. Furthermore, individual interviews were conducted at the end of the training to gain a better understanding of their experiences and to collect more reliable feedback related to the three evaluation components.

In the case of a game-based activity, creating the game is not an easy task. It must be designed with careful consideration of several aspects to ensure it becomes an effective training approach, striking the right balance between the serious, educational component and the engaging, playful element of the game (Caserman et al. 2020).

The scenario should be continuously applied and improved, with different versions tailored to emerging job roles. While we focused on Industry 5.0 Assembly Line Operators, this approach could easily be adapted for maintenance or other fields as well. To address emerging jobs and industry needs, collaboration among employers, education and training providers, and researchers is essential to align training with evolving industry requirements and effectively bridge these gaps (Braun et al. 2024). Additionally, all frameworks for skills and competencies must be updated to reflect the needs of Industry 5.0.

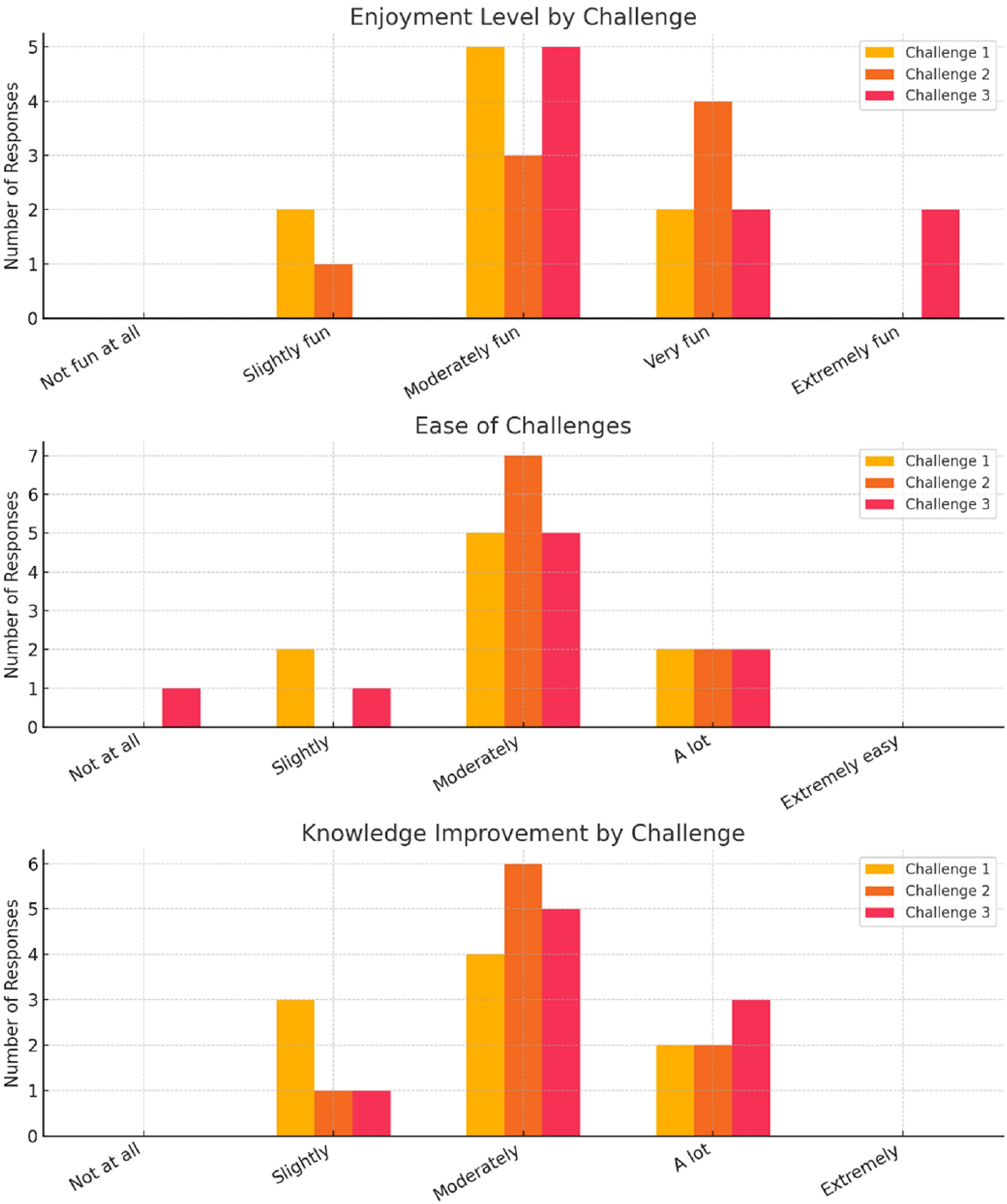
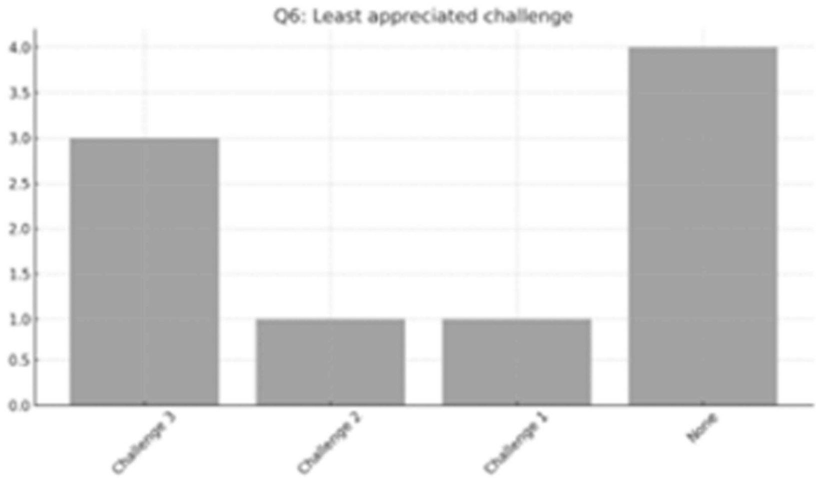
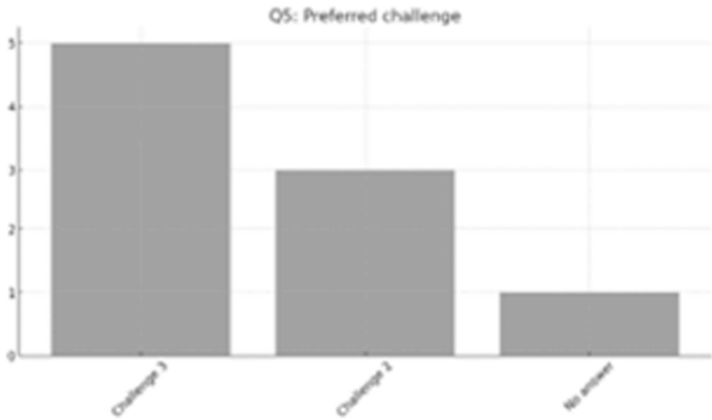


FIGURE 6 | Trainees perceptions of the three challenges (part1). [Color figure can be viewed at wileyonlinelibrary.com]

For example, the ESCO framework (Chiarello et al. 2021) should be continuously revised to respond to these evolving demands. An evaluation of the regional skills ecosystem based on recognized models, such as the SEM Skills Ecosystem Model, is necessary to identify existing gaps. It is essential to consider both the vertical dimension (state levels and policies) and the horizontal dimension (local interactions) with good leadership in order to build a truly effective training ecosystem that fosters collaboration (Wedekind et al. 2021) and addresses the market needs.

Q4 : What participants appreciated most	
P1, P2,P3,P4	Hands-on work with machines
P5	Challenges and exploration of technologies
P6	Various real-work activities
P7	The overall scenario
P8	The challenges
P9	The mix of Fun and learning





Q7 : Elements not appreciated, to be improved	
One participant	Integrate playful activities into the first part of the training
One participant	More explanation of the challenges
Three participants	More time
Four participants	None

Q8 : Would you recommend this training	
P1	"Yes, it's an innovative new training method."
P2	"Yes, it's the best way to get a feel for the jobs of the industry of the future."
P3	"Yes, because with games, complex topics become easy to understand."
P4	"Yes, because we have the opportunity to see concrete elements related to the industry of the future and to work with technologies."
P5	"Yes, because with these training methods (factory-school and challenges), you acquire skills quickly."
P6	"Yes, it made me want to learn more; it's interesting to me."
P7	"Yes, with these training approaches, we were not bored but rather attentive and engaged; time passed quickly."
P8	"Yes, this approach is very relevant for fostering familiarity with Industry 4.0."
P9	"Yes, because through these approaches, you retain a lot of information."

FIGURE 7 | Perception assessment responses (part 2).

Assembly Line Operations, the subject of the present Industry 5.0 training, are based on production development, production planning, and the MES. These elements have also been recommended by some organizations, such as the Ministry of Education, Youth and Sports of Baden-Wuerttemberg, for integrating Industry 5.0 content into vocational school curricula (Löhr-Zeidler et al. 2016).

Our training has also emphasized the importance of raising awareness about Industry 5.0 and the central role of humans in this transition. That's why the *Industry 4.h* chair aims to promote inclusivity by including job seekers, NEETs (Not in Education, Employment, or Training), and people with disabilities, a key pillar of Industry 5.0. We believe that Industry 5.0 can be a powerful tool to help humanity, supporting corporate responsibility and addressing global challenges such as poverty, hunger, and more (Bai et al. 2020).

To explicitly address our Research question, "How can LFs be used to train individuals without an industrial background in Industry 5.0 within a VET context?" our findings demonstrate that the LFBT approach constitutes an effective and operationalizable solution. The pilot study confirms that immersive, scenario-based training within a realistic production environment enables participants with no prior industrial experience to progressively acquire both conceptual understanding and practical skills required for Assembly Line Operations. Through the structured integration of hands-on activities, role-based tasks, and game-based challenges, the LFBT framework successfully translates abstract Industry 5.0 concepts into tangible learning experiences. The positive outcomes observed across the three evaluation dimensions, knowledge acquisition, skills development, and learner perception, provide empirical evidence that such environments not only facilitate learning but also enhance engagement and confidence among trainees. LFs serve not merely as technological platforms, but as pedagogical ecosystems capable of bridging the gap between non-industrial populations and the evolving requirements of Industry 5.0, thereby contributing to more inclusive workforce integration and reducing the risk of inequality and unemployment.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Assoc. Prof., Economic Education Department of STKIP PGRI Jombang, East Java Indonesia, agustkip@gmail.com, Prianto A, Winardi W, Assoc. Prof., Civic Education Department of STKIP PGRI Jombang, East Java Indonesia, win.stkipjb@gmail.com, Qomariyah UN, Mathematic Education Department of STKIP PGRI Jombang, East Java Indonesia, umi.stkipjb.gmail.com. 2021. "The Effect of the Implementation of Teaching Factory and Its Learning Involvement Toward Work Readiness of Vocational School Graduates." *International Journal of Instruction* 14, no. 1 (January): 283–302. https://doi.org/10.29333/iji.2021.14117a.

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Annex 1

Knowledge Assessment

Full Name: ____________________________

1.

List four technologies and their applications (use cases) within a production plant environment:

....

....

....

....

2.

What are the three key dimensions integrated into Industry 4.0 that contribute to the transition toward Industry 5.0?

....

3.

Explain the difference between Augmented Reality (AR) or Mixed Reality (MR) and Virtual Reality (VR):

....

....

4.

State one positive impact on humans:

....

5.

State one advantage for the company:

....

6.

List some functions of a Manufacturing Execution System (MES):

....

....

....

Annex 2

Perception Assessment (Anonymous)

Part 1

1. How would you rate your level of enjoyment while completing the following challenges?

	Challenge 1: Recognizing Technologies	Challenge 2: AR Explorer Mission!	Challenge 3: Managing Customer Orders
Not fun at all			
Slightly fun			
Moderately fun			
Very fun			
Extremely fun			

2. Was the challenge easy to understand and complete?

	Challenge 1: Recognizing Technologies	Challenge 2: AR Explorer Mission!	Challenge 3: Managing Customer Orders
Not at all			
Slightly			
Moderately			
Very			
Extremely easy			

3. Did you feel that the challenges improved your knowledge or skills in the relevant domain?

	Challenge 1: Recognizing Technologies	Challenge 2: AR Explorer Mission!	Challenge 3: Managing Customer Orders
Not at all			
Slightly			
Moderately			
Significantly			
Extremely			

Part 2

4. What did you appreciate the most about this training?

....

5. Which challenge did you enjoy the most? Why?

....

6. Which challenge did you not enjoy? Why?

....

7. Were there any elements you did not like or that could be improved?

....

8. Would you recommend this training (including the challenges) to others? Why?

....