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On a heuristic evaluation system for Industry 5.0 with respect to interventions: the case of training in businesses

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Abstract

Manufacturing has been undergoing many changes, with the latest one being the paradigm shift to Industry 5.0. In this long procedure, training is required at any level, from operators to managers. Thus, interventions must be made so that Teaching and Learning Factories are upgraded towards integrating Industry 5.0. To this end, an evaluation system has to be made, assessing the feasibility of the three pillars' integration. This procedure can concern a qualitative assessment (or a quantitative one) of the feasibility and the other implicated concepts, such as upskilling. At the same time, multilevel metrics are relevant, such as Key Performance Indicators (KPIs) related to company practices, manufacturing itself, jobs and trainees. Herein, a summative differential evaluation scheme, based on heuristic aspects, is explored, under the framework of the aforementioned TLF interventions. Examples of companies' ex-ante characterization are given. Then, potential extensions are being discussed towards achieving formative evaluation and potentially towards KPIs.

Keywords: Industry 5.0; Evaluation; Training; Teaching Factory

1. Introduction

Manufacturing is the process of transforming raw materials into finished products with the help of various processes, machines and operations. It plays a critical role in the economy [1], enabling both mass and customized production of goods, contributing to employment and fostering innovation. By leveraging advanced technologies, optimizing processes and focusing on sustainability, manufacturers can improve efficiency, reduce costs and meet the ever-changing demands of the global market [2].

It is well known that manufacturing is a dynamic and evolving sector that requires continuous innovation and adaptation. Industry 5.0 represents the next evolutionary step in manufacturing, emphasizing collaboration between humans and advanced technologies such as artificial intelligence (AI) and robotics [3]. This human-centered approach aims to elaborate personalized, sustainable and efficient production

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processes [4]. This would dictate the change of strategies within a company, integration of technology, change of workflows, communication patterns and training [5]-[7].

In several cases, some of the technical benefits of incorporating Industry 5.0 into manufacturing can be seen directly on the production line and in the final product. A key benefit, beyond the three pillars (sustainability, human-centricity and resilience) can be improved productivity and efficiency, which is documented in literature [8]. One of the examples of this relationship is the following; human-robot collaboration leads to more efficient and innovative manufacturing processes, as the robot takes on the most difficult or repetitive tasks instead of the human. Also, Unlike traditional industrial robots that operate in isolation, cobots in particular [9] are designed to work safely alongside humans, helping with tasks that require precision and repetition while allowing humans to focus on more complex and creative activities [1]. In other cases, the concept of efficiency can occasionally be contradictive to the integration of Industry 5.0, however, extra concepts could be built to address this fact, or the definition of such concepts could be generalized. With respect to this work, a Teaching Factory or a Learning Factory lie in the core of the training system, addressing simultaneously an internal need.

As a result, production systems have become more adaptable to change, demand and disruption. Flexible manufacturing systems can switch between different products with minimal downtime, improving responsiveness to market changes. However, achieving this requires improved coordination across the supply chain to reduce delays and manage logistics and inventory more efficiently [10].

In addition, this collaboration contributes to the sustainability of production processes. AI systems analyze vast amounts of data to optimize production processes, predict maintenance needs and improve quality control. Machine learning algorithms enable continuous improvement through data-driven insights [11].

Industry 5.0 addresses the problem of unnecessary depletion of natural resources by promoting sustainable practices, optimizing resource use, reducing waste and minimizing environmental impact. In addition, it emphasizes the use of renewable energy sources, the recycling of materials and the design of products with a longer life cycle [12].

Advanced robotics and AI help reduce the chance of errors in the production process or the way a product is made, ensuring greater consistency in product quality and reducing the unnecessary use of raw materials due to failure.

Finally, continuous learning and adaptation to new tools and processes is very important for the workforce. It increases his cognitive level and strengthens his professional self-confidence. This realization gave birth to the need for the teaching factory (TF) [13]. The Teaching Factory (TF) [14] is a collaborative space where technicians and engineers bring factory experience to teach students, while students and faculty bring classroom knowledge to teach first-hand. This collaboration is an ongoing process, with regular sessions and ongoing interaction between the factory and the classroom. The main concept we focus on here is that of problem solving. Teaching factories are based on a didactic concept that emphasizes experiential learning. Philosophy focuses more on students' experiential learning in real-world problem solving and critical thinking, applying theoretical knowledge to practical scenarios.

Educational specialists contend that new competencies only succeed if action-based learning and comprehension-based learning are combined [15]. Therefore, the attention has been to creating more practice-based learning environments. However, the assessment of outcomes and evidence of these teaching factories (and also Learning Factories) remains limited [16], mainly because of the inaccessibility of these interventions [17]. Those interventions that require engagement at the company level are classified as Teaching & Learning Factories. The receivers of the training can be both operators and managers [18].

The framework of applying training is based on the concept of interventions, which has been defined in social sciences a long time ago [19]. The term is tentatively used herein, as Industry 5.0 is a multi-disciplinary term, however, it has been previously used to describe targeted experiments in companies with respect both Industry 4.0 (digitalization) [20][21] but also for Industry 5.0 aspects, such as safety [22]. However, for use herein, this concept has been restricted to “aiming at change the Teaching & Learning Factories-training (TLF) intervention”. The generic gap addressed here, is the integration of Industry 5.0, mainly by companies. This is accompanied by a variety of challenges, i.e. technical and human [8]. More specifically, the integration that is considered here is in terms of training, potentially followed by extra concepts [23]. Training of personnel, such as operators and engineers, is of crucial importance to the introduction to Industry 5.0 [24][25], however, herein, the overall objective is to verify that Industry 5.0 characteristics can be integrated into training systems.

Regarding relevant material on questionnaires and assessment, for the case of sustainability, there are specialised questionnaires from B Corporation that offer possibilities towards sustainability certification [26], as well as there are similar procedures foreseen in ISO 14001:2015. For human centricity, there are extended questionnaires from Workplace Innovation, while for resilience, APMG has a program [27] and Centric Consulting has a business-focused assessment questionnaire too [28]. However, these exceed the purposes of the training, which is the focus here.

To be more specific, the TLF 5.0 concept is regarded and the aim of this work is to design a heuristic summative evaluation system [29], with the help of experts from real case studies in companies, where such interventions will occur, given that technologies have already been identified, so there is no need for extra steps (i.e. [30]).

2. Setting the requirements

The aforementioned interventions regard integrating the three pillars, namely human centricity, sustainability and resilience intro training systems. The methodology to do so, is in line with job and company modelling and can be found in literature. Four different companies have been used to this end, but also additional three companies with partial interventions have been regarded. A “partial intervention” involves the

consideration of less than three pillars. The evaluation procedure is applied before and/or after the intervention, towards assessing the integration of Industry 5.0 through training (TF) and at the same time, verifying the alignment with some technical objectives [31], such as making such interventions future-proof. As a matter of fact, the following axes of interest need to be taken into consideration, as extensions of the aforementioned objectives: (1) Upskilling, (2) Feasibility of the intervention, (3) Multilevel mentality change, (4) Involvement of companies practices [32], (5) Efficiency of the respective technologies integration with respect to internal aspects, (6) Directions expressing the motivation, as stated in BRIDGES 5.0 Deliverable 1.1 (D1.1) [33]). It is noted that the companies involved in this procedure either did not have initially any training system, or they had not taken deliberately Industry 5.0 characteristics in them.

The evaluation can be self-driven for the most part, implying that the companies themselves eventually report on the feasibility of integrating Industry 5.0 into their training systems. Whenever required, external experts have contributed to both the design and the evaluation. Also, to make sure that the questions and the responses are relatively concise, externals "intervention leaders" have been defined.

After filling in the template related to designing the intervention [13], the intervention leader is responsible of gathering the responses, engaging the involved actors (trainees, managers, etc). He also has the possibility of involving external actors for the design (i.e. technology communication experts), the implementation (i.e. system integrators), the intervention itself (i.e. trainers) or even for the evaluation (i.e. experts to enrich the questionnaires and help populating them with data).

In any case, the six axes cannot be measured directly, due to the complexity of the codependences and the measurements [34]. To this end, the axes were re-distributed as priorities into eight tables. Table 1 is about human and jobs, in terms of upskilling. The questions of Table 1 hereafter are indicative and highly relevant in the four used cases. Their focus is apparently human centricity and resilience.

Table 2 concerns the intervention procedure itself. Table 3 regards the study of whether there is room for company engagement in terms of organizational changes. Table 4 is relevant to special focus on impact on mentality; for this, it was presumed that management has a leading role in cultivating concepts and creating experiences [35]. This implies that the role of managers is central to achieving human-centric workflows in particular, within the company; holistic understanding driving a "vision of digital transformation", or having a "culture of change", among other policies are relevant in Industry 5.0 [36]. This can be achieved in different ways; the way that is quite convenient here, is to have as target groups in training not only operators, but also engineers and/or managers. Also, Table 5 is making a link potentially to company practices. A follow-up study will document these.

The objective of these four tables is to characterize qualitatively the establishment of the training within the company in the sense of connecting it with surrounding practices. The goal is to have a qualitative evaluation against each other of these "interventions" with respect to:

- how invasive they are within the company
- what structural and organizational changes they come with
- if they are robust enough with respect to future needs
- if they can be supported within the company by various departments and how much engagement they require.

The questions therein are not exclusive in any case, they are just a summary of the needs of companies and knowledge from previous activities and theoretical background / practices [37]. To this end, they concern only textual response. The way to process them is through careful qualitative review, through techniques such as a semi-structured interview. The processing of the results from social, management, technical and financial scientists has to be performed.

Then, three tables follow, regarding the company side and exactly to what extent the three pillars have been finally integrated: Table 6 on human centricity, as the first pillar of Industry 5.0, Table 7 about sustainability, focusing on environment (as per the European Commission [38]) and finally, Table 8, related to resilience, focusing mainly on supply chains, potentially extending to production itself.

Adopting the wording of the Organisation for Economic Co-operation and Development (OECD), for reasons of completeness, [39], which is related to the results chain [40], the following can be claimed, regarding an Input-Output modelling of the educational procedure:

- "Input" is consisting of existing educational structures, need for Industry 5.0 pillars, existing personnel and existing problems
- "Process" is related to the TLF 5.0 and the evaluation procedure
- "Output" is the tuple of upskilling, integrating solutions and integrating Industry 5.0 pillars
- "Outcomes" can be considered to be the contributions to both job transformation and business transformation and the definition of procedures that will lead to practices.
- "Impacts" refer to the short to mid-term future and what can be considered here is the adoption of Industry 5.0 practices.

3. A first approach

Taking into account the fact that, given the lack of standards for resilience and human centricity mainly, new KPIs will only complicate modelling. Thus, qualitative and heuristic metrics are used to express the efficiency of the interventions.

The evaluation consists of two parts; part A is about the intervention itself, focusing on the job and the technologies, while part B aims at studying the role of the company itself and the respective engagement.

All parts utilize a heuristic Likert scale: 5 - Extremely high, 4 - Moderately high, 3 - Neutral, neither high nor low, 2 - Moderately low, 1 - Extremely low.

It is essential that justification is provided as well, so that the subjectivity is reduced. The justification can include the current status of the company or trainee, accompanied of what the maximum (5) of the scale refers to. Below, the questionnaire is presented. "Before" and "after" are denoting the time point that the questions are put with respect to the intervention. The goal is to have a differential assessment and study the evolution due to the intervention. Figure 1 is

indicative of the workflow, pointing out the "before" and "after" as ex-ante and ex-post evaluation, respectively. The questions that are presented hereafter are a result of (a) brainstorming and (b) common requirements of the aforementioned companies. The way the results are processed is different, based on the focus of evaluation. For quantities characteristics, such as upskilling, where statistical analysis is required, the procedure consists of the following phases: anonymization, averaging across categories, difference between ex-ante and post-ante (if applicable) and finally, averaging along cases. Justification is required, to analyze any potential issues pertaining to subjectivity. For qualitative analyses, i.e. the suitability of practices, an analysis is required to extract potential positive and negative attributes.

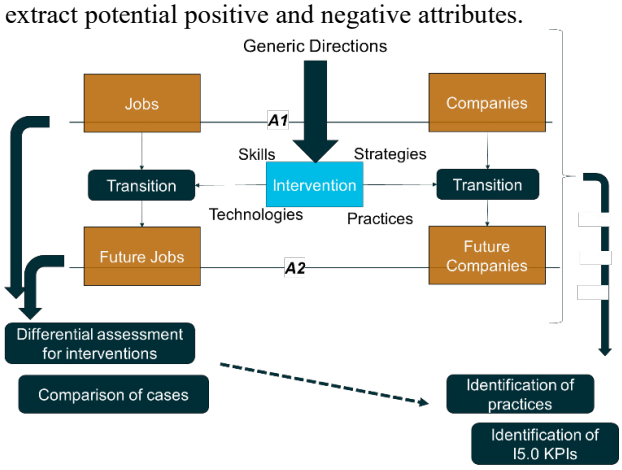

Fig. 1. Evaluation scheme applied in a generic intervention design workflow. Time is the vertical axis. A1: ex-ante assessment, A2: ex post assessment.

The first five tables are presented hereafter. They consist the part of the questionnaire related to the Intervention evaluation. The responses desired are Likert 1-5, with 5 being maximum positive, unless otherwise stated. Justification is expected at all cases.

Table 1. Upskilling (before and after)

Question (for trainees)
Do you feel confident in solving problems during the manufacturing process?
Do you feel confident in using shared control between human and machine?
Do you feel confident in working in different project at the same time?
Do you feel confident in working in different working areas in the company?

Table 2. Usefulness, Ease & Impact of intervention (after)

Question (only text expected)
How easy was to implement the intervention?
Is the intervention generic enough to be of interest to other groups?
How easy is it to extend the intervention within the company, to other departments?
How are groups of operators and managers involved in the design/ implementing of the intervention? Are they given time and resources required to enable their active involvement? If not, please explain why.
What aspects would you add to such interventions, so that you achieve targets, such as management structure change?

Table 3. Implications for organizational changes (before)

Question (only text expected)
Is senior management committed to the intervention? How do you know?
Who are the principal stakeholders (individuals or groups who have been affected by the intervention and/or whose support is necessary for its success)? Have their roles and potential contributions been clearly defined, and if so how? Are trade unions or employee forum representatives involved as active participants?
What are the intended outcomes in terms of company performance?
How will the delegation of decision-making affect the existing management structure and management roles?
How will the intervention contribute to achieving your company's strategic goals?

Table 4. Implications for mentality changes (after)

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

Table 5. Engagement of company in terms of practices (before)

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

The next part of the evaluation has three sub-sections, where the pillars are the main study, from the perspective of the company.

Table 6. Human centricity

Question
Will there be/are there changes in mentality of the work among the trainees-employees?
Will reduction of physically arduous tasks be achieved? *(1,3,5 with justification)*
How effectively does this company support and implement worker participation in decision-making processes related to both change initiatives and daily operations?
How effectively does this company support the implement worker empower its participants through, inclusive decision-making, and fostering inclusivity?
How effectively does this company support and implement opportunities for day-to-day learning?
How effectively does this company support and implement opportunities to reduce monotony?
How effectively does this company support and implement enhanced work autonomy for frontline workers?
How effectively does this company support and implement employee-driven improvement and innovation?
(FROM D1.1 DIRECTIONS) Does the company support and implement shared control between humans and machines? *(1,3,5 with justification)*

(FROM D1.1 DIRECTIONS) To what extent does the company promote delegation of decision-making from managers to workers?

Table 7. Sustainability

Question
To what extent does the company promote and engage in reductions in energy consumption?
To what extent does the company promote and engage in reduced CO2 output?
To what extent does the company promote and engage in waste reduction?
To what extent does the company promote and engage in greater reuse and recycling of materials?
To what extent does the company promote and engage in life cycle analysis?
To what extent does this company work towards reducing primary energy consumption?
(FROM D1.1 DIRECTIONS) To what extent does the company promote and engage in caring about the environment?
(FROM D1.1 DIRECTIONS) To what extent does the company promote and engage in making and promoting green choices?

Table 8. Resilience

Question
Are procedures robust within the company? (1,3,5 with justification)
Is time of recovery used as KPI in company procedures? (1,3,5 with justification)
To what extent does the company promote self-organised teamwork?
To what extent does the company promote the flatter organizational structure?
(FROM D1.1 DIRECTIONS) Does the company encourage creativity and flexibility in manufacturing processes? *(1,3,5 with justification)*
(FROM D1.1 DIRECTIONS) Does the company encourage innovation? *(1,3,5 with justification)*
(FROM D1.1 DIRECTIONS) To what extent does the company promote and engage in resilient supply chains?
(FROM D1.1 DIRECTIONS) To what extent does the company promote and engage in the implementation training and education systems that guarantee the availability of knowledge and skills?

4. Results on the companies' landscape & discussion

Herein, the four indicative and available companies, where full interventions will take place, have been chosen. The goal is to check applicability of the evaluation template in the ex-ante evaluation and to showcase the illustration of data presentation. Nevertheless, the diversity in terms of sector, application, starting and country is large, as shown in Table 9.

The interventions plan regards a mixture of quantitative (i.e. a comparative research, with Likert scales for upskilling, but still with elements of field research) and qualitative studies (i.e. a case study for feasibility of Industry 5.0 integration and for practices extraction) [41]. As such, the statistical significance in its probabilistic form is not always the focus [42]. Instead, the transferability is of interest; here, the crucial] requirements (i.e. leading edge of change and member checking) [43] are met. As a matter of fact, the number of companies, has been an outcome of convenience sampling [44], while for the number of trainees in each company, snowballing or even typical sampling will be used (this, however, exceeds the purposes of the current work). For the evaluation herein, tables 6-8 have been used, so that the ex-ante characterization of the companies has been utilized towards illustration of data visualization.

Table 9. Descriptive characteristics of the four main companies

Description & Incentive	Desired outcomes
Two different Manufacturing Companies, interested in digitalization (averaged used)	Technology integration
Semiconductors Company, interested in new department operating smoothly	Knowledge documentation and transfer
Batteries company, interested in creating holistic training system	Workplace-related attitude change
Company about Robotics & Automated manufacturing processes, interested in expanding the internal training system	Technology transfer and problem solving

The methodology to estimate their overall characterization is depicted in Fig. 2. Firstly, all the responses are gathered per company and per pillar. Then, for each company, the responses' average (mean value) are estimated per characteristic (i.e. pillar). Herein, if some responses were left blank (e.g. because they are not currently the focus), they were ignored and the mean value was estimated on the rest of the questions.

After obtaining the aforementioned characterization of each of the companies per pillar (HC_n for the human centricity, R_n for the resilience and S_n for the sustainability of the n-th company), an overall metric x_n for each company was estimated, as per Eq. 1.

Next, Eq. 2-4 were used for the statistical measures of minimum, average and maximum overall Industry 5.0 metrics, across all companies, utilizing operators *min*, *max* and *mean* standing for minimum, maximum and average (mean value), respectively.

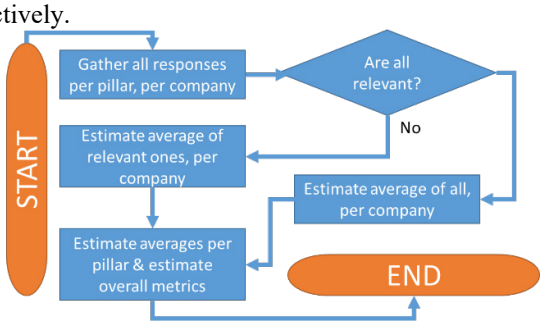

Fig. 2. Methodology of evaluation

The same was performed for each pillar separately, as per Eq. 5-7. Thus, the overall indicators HC, R and S for Human Centricity, Resilience and Sustainability across all (four) companies, respectively, can be estimated.

$$x_n = (HC_n + R_n + S_n)/3 \quad (1)$$

$$x_{min} = min(x_n) \quad (2)$$

$$x_{av} = mean(x_n) \quad (3)$$

$$x_{max} = max(x_n) \quad (4)$$

$$HC = mean(HC_n) \quad (5)$$

$$R = mean(R_n) \quad (6)$$

$$S = mean(S_n) \quad (7)$$

Figure 3 is representative of the results of the ex-ante evaluation. In particular, in the top picture, the distribution of the pillars' metrics along pilots is given. It can be seen that four companies, denoted in different colours, obtain different values for human centricity, sustainability and resilience readiness, as this is obtained by HC_n, S_n and R_n, respectively. It is evident that there is some range present, up to two Likert degrees.

The respective average values are shown in the bottom figure. These mean values indicate some modesty in the results, showing some room for improvement. This is probably due to the fact that different technologies and techniques can be applied in different cases.

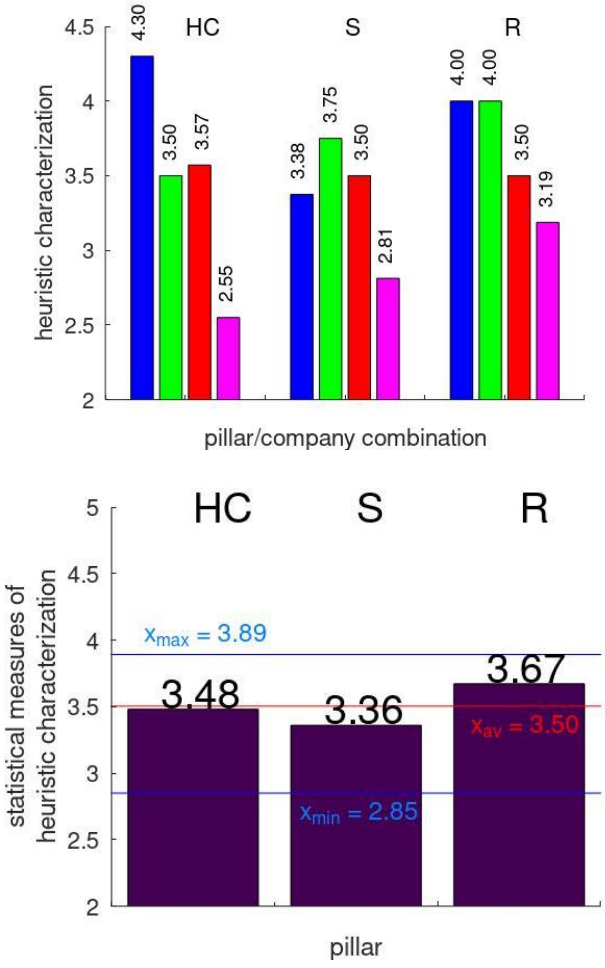

Fig. 3. Evaluation of the companies before the interventions: detailed along pilots and pillars (top) and aggregative (bottom).

Additionally, the overall assessment diagram involves the statistical values for the overall Industry 5.0 assessment, annotated with continuous lines. This implies the synergistic effect of the three pillars, leading to mean value of 3.5/5, while the maximum and minimum values of the overall Industry 5.0 metrics have a difference of approximately one Likert degree ("range" in statistics). Probably, a lot of techniques could affect the score on more than one pillars. However, skills taxonomies are not elaborate enough so that they take into account such cross-affecting factors (with the exception, maybe of fusion skills [45]). Also, especially with concepts such as super-teams (the collaboration between humans and technology as per Deloitte [46]) it may be mandatory that more complicated models are taken into consideration.

Taking into account the company engagement, it appears that both practices from companies and focus on transforming jobs are relevant into enhancing the current image. The Likert scale, however, being in its nature heuristic, could lead to inconclusive measures. Thus, more quantified results metrics can be elaborated in parallel. The definition, however, is case-dependent. Also, while the metrics can be linked to productivity, monetary values, or even physics, the current questionnaire could be used in terms of root cause identification, or even Industry 5.0 related Failure Mode and Effects Analysis (FMEA).

5. Conclusion & future work

It is evident that the current evaluation system can be a first approach towards assessing a company with respect to Industry 5.0. In fact, partial scores could be indicative of potential areas that need optimization, while the value of interventions can also be quantified.

However, the definition of an Industry 5.0 compliant company is not quantified to a desired extent. As such, elaborated metrics are needed, also for certification.

Furthermore, the existence of many different interventions will help constitute a statistically significant mass of results pertaining to "proof of concept" towards the feasibility of Industry 5.0 in training systems. In any case, the European background of companies in terms of financial, social and technical characteristics is quite diverse.

Also, further work is required towards generalizing the interventions towards other directions, such as absorbing technology and creating more structural changes than the ones required for creating new or modifying existing training sessions. It seems that the integration of Industry 5.0 requires multi-disciplinary task forces and can be quite case-dependent. In any case, frameworks (and templates) for designing and evaluating relevant activities are highly useful.

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