Available online at www.sciencedirect.com

ScienceDirect

IFAC PapersOnLine 59-10 (2025) 2563–2568

Bridging Tradition and Innovation in Training: Evaluating and Comparing Training Methods Through a Comprehensive Framework

Oscar Escallada * **Eva Geurts** ** **Serkan Solmaz** ***
Maitane Mazmela * **Ganix Lasa** *

* *Design Innovation Center (DBZ), Mondragon Unibertsitatea - Faculty of Engineering, Loramendi, 4, 20500 Arrasate-Mondragón, Gipuzkoa Spain.(e-mail: oescallada@mondragon.edu).*
** *UHasselt - Hasselt University, Digital Future Lab, Flanders Make, Diepenbeek, Belgium (e-mail: eva.geurts@uhasselt.be)*
*** *Flanders Make, Leuven, Belgium (e-mail: serkan.solmaz@flandersmake.be)*

Abstract: Developing a highly competent workforce is essential for meeting the evolving demands of modern manufacturing. In this context, evaluating traditional and innovative training methods plays a critical role in enhancing the effectiveness of assembly processes. With a range of options—such as on-the-job training, classroom training and eXtended Reality solutions—it is critical to identify the most appropriate training approach for different contexts. Therefore, we performed a literature review and visited manufacturing companies to gain an overview of metrics involved in the assessment of training methods. To support this, we developed a comprehensive framework that guides the selection of such approaches. Our research identified key factors that contribute to training, which are integrated into the framework. The framework is designed to evolve alongside technological and contextual changes, allowing for ongoing adjustments as new strategies emerge or existing ones improve, such as decreasing Virtual Reality costs or personnel limitations impacting traditional training. This adaptability ensures the framework remains a reliable resource for making informed training decisions, tailored to specific needs while accounting for an ever-changing industrial landscape.

Keywords: Industry 4.0; Knowledge management in production; Decision-support for human operators; Training methods; Assembly training; Industry 5.0

1. INTRODUCTION

The manufacturing sector is undergoing a significant transformation, largely driven by advancements in automation, digital technologies, and Industry 5.0 principles (Schwab (2017)). This transformation is characterized by integrating physical production systems with advanced digital technologies, creating smart factories where machines, systems, and humans work. The increasing adoption of technologies such as robotics, the Internet of Things (IoT), and artificial intelligence (AI) has revolutionized manufacturing processes, driving operational efficiency, customization, and adaptability. However, these technological changes bring with them a parallel challenge: the need for a highly skilled workforce capable of adapting to new roles, learning new skills, and operating sophisticated machinery (Brynjolfsson and McAfee (2014)). As such, effective and efficient workforce training has become a critical component of modern manufacturing. Manufacturing environments require a variety of training methods to ensure that workers can acquire the necessary skills and knowledge. Traditional methods, such as on-the-job training (OJT) and classroom-based learning, have been effective in transferring fundamental skills crucial for operating machinery and ensuring basic safety. In contrast, emerging technologies such as Augmented Reality (AR) and Virtual Reality (VR) offer promising alternatives to traditional training approaches (Palmas et al. (2019)). Training programs using AR or VR have the potential to support individual learning, but they remain largely unpersonalized (Pimminger et al. (2021)). In addition, these technologies allow for the creation of detailed simulations of complex tasks, allowing workers to practice skills in a controlled environment and receive immediate feedback, which has been shown to significantly improve skill acquisition and retention (Huang et al. (2021)).

The key contribution of this work is a framework for selecting training methods in manufacturing, developed through an analysis of traditional and digital approaches to identify key effectiveness metrics and contextual factors. This framework supports decision-makers in choosing appropriate methods, optimizing workforce skill development with greater efficiency and effectiveness.

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2025.09.431

2. CURRENT TRAINING METHODS

2.1 Traditional Training Methods

Traditional training methods have long been the cornerstone of skill development in manufacturing, encompassing classroom training and OJT expert guidance. Each approach offers unique advantages and limitations depending on the context.

Classroom-based Training: Classroom-based training involves structured learning sessions, typically led by an instructor, where theoretical concepts are explained before being applied in practice. This method is particularly effective for imparting foundational knowledge, such as safety protocols, production theory, or understanding technical diagrams (Bacca Acosta et al. (2014)). Classroom learning provides an environment where trainees can ask questions and interact with peers. Furthermore, it can be challenging to tailor the content to the varying needs of individual learners, resulting in a one-size-fits-all approach that may not be effective for all trainees (Freina and Ott (2015)).

Expert Help in Manufacturing Training: Expert help in manufacturing, which integrates on-the-job training with mentorship, is vital for developing skills. Trainees work on real tasks under the guidance of experienced workers, acquiring practical, role-specific abilities (Burke and Hutchins (2008)). One of the strengths of this approach is its ability to provide immediate feedback and address specific challenges trainees face. It also facilitates the transfer of knowledge that is often hard to capture in formal training programs. However, training depends heavily on the availability of skilled mentors, and the quality of learning can vary based on the mentor's ability to teach (Psarommatis et al. (2023)). Additionally, safety risks, disruptions to production, and the high costs of personalized training make it challenging to scale (Liu et al. (2022)).

2.2 Digital Training Methods

Virtual Reality (VR): VR offers fully immersive learning experiences, allowing workers to engage with realistic simulations of their work environment (Palmas et al. (2019)). VR immerses users entirely in a virtual setting, enabling them to practice tasks in a safe and controlled environment. This is particularly beneficial for hazardous tasks or complex procedures (Wolfartsberger et al. (2023)). Engagement caused by VR improves information retention (Ip and Li (2015)). VR supports standardized training, ensuring consistency in instruction regardless of an employee's physical location (Bacca Acosta et al. (2014)).

Augmented Reality (AR): AR integrates virtual elements into the real world, offering a more hands-on experience as trainees interact with both virtual objects and their physical surroundings (Palmas et al. (2019)). This enhances the sense of realism, making it particularly effective for tasks requiring spatial awareness and coordination. Like VR, AR provides a safe environment for practicing complex or hazardous tasks (Wolfartsberger et al. (2023)), but its added connection to real-world elements may lead to even greater applicability in certain manufacturing contexts.

Digital Work Instructions (DWI): DWIs are increasingly used on the work floor, accessible via devices such as tablets, smartphones, or AR glasses. These tools provide a dynamic, on-demand platform for training, allowing operators to access information as needed and learn at their own pace (Pimminger et al. (2021)). Digital work instructions support flexibility and personalization, enabling workers to focus on specific tasks or refresh their knowledge without disrupting workflows. On the other hand, it requires the material preparation.

The comparison between digital and traditional training methods in manufacturing is a topic of ongoing research in which different papers have performed reviews comparing various training methods (e.g. Daling and Schlittmeier (2024)). However, a comprehensive framework for consistently evaluating and comparing these methods remains lacking.

3. METHODOLOGY

The methodological approach adopted for this research aimed at providing a comprehensive review of existing training methods in manufacturing, focusing on both traditional and digital approaches. This section outlines how the review was structured, the characteristics of the training approaches considered, the specific training methods analyzed, and the metrics used to evaluate them. The analysis involved both an extensive literature review and peer evaluations, incorporating insights from multiple studies to ensure a robust and well-rounded perspective on training metrics and effectiveness.

3.1 Review

To develop an in-depth understanding of the training methods used in manufacturing, we conducted a review based on academic literature and expert opinions. The review aimed to identify, categorize, and assess training strategies for manufacturing. The experts include individuals responsible for the training and career planning of operators within manufacturing companies. We sourced papers from IEEE Xplore, ScienceDirect, and SpringerLink due to their broad coverage of engineering and technology and their rigorously peer-reviewed publications, ensuring a comprehensive and credible set of studies. The training methods analyzed in this review were systematically categorized into traditional and digital approaches. A summary of the training methods considered is presented in Table 1. The training methods were evaluated based on their application in specific manufacturing contexts, focusing on the task type, environment, and technology used.

The review of training methods highlights the diversity in approaches employed across various studies, reflecting the breadth of needs and technological advancements in workforce training. VR methods are extensively explored showcasing their immersive and interactive potential. Additionally, one study investigates the integration of VR with AI, demonstrating its potential for enhancing adaptability and personalization in training. AR methods are also prominent, with some focusing on AR Head-Mounted Displays (HMDs), some others on handheld AR devices,

Table 1. Overview of training methods present in literature

Group	Training methods	Number of papers
VR	VR + AI	1
	VR glasses	11
	Screen-basedVR	11
AR	AR headset	6
	AR handheld	7
	AR projection	3
Classroom-based training	Classroom	1
Expert help	On the job Expert help	7
Digital & written instructions	Paper-based	8
	Video-based	2
	Desktop app	2
	Supported with physical 3D elements	2

and three on AR projection systems. These studies emphasize AR's capability for real-time, contextual guidance, particularly in tasks such as maintenance and repair. Other methods include classroom-based training, expert mentorship or on-the-job training, and digital or written instructions, such as paper-based approaches, video-based learning, and training supported by physical 3D elements.

3.2 Identified Metrics

We often see metrics like task execution time being used to measure training effectiveness, yet their selection is often arbitrary and variable. This literature review addresses this inconsistency, emphasizing the need for a comprehensive framework to guide the assessment of training effectiveness across diverse methods. Metrics were gathered from reviewed papers and peer-reviewed expert ratings. We collected all metrics investigated in the papers from Table 1 which confirmed the huge variety of training metrics and limited structure present. Table 2 shows an overview of the metrics we encountered.

Performance was the category most analyzed, represented by diverse metrics. Next to a set of objective metrics, we also encountered subjective measures, such as *usability of the training* or *perceived engagement* or *presence*. This result highlights the need for a more structured approach, in which results can be better aligned with all aspects related to training.

3.3 Company Visits

We visited five manufacturing companies, including two sheltered workplaces, to understand their training practices. On the work floor, we observed daily routines and conducted interviews with key training personnel. These companies mainly focused on assembly work (e.g., assembling windows or electrical cabinets). The interviews provided insight into their training methods, competency assessment, and employee development strategies. Although training was generally planned based on operational needs and regulatory requirements, companies lacked structured insight into the impact of learning or the most effective training methods. OJT training and DWIs were common relying on experienced staff for guidance, whereas classroom sessions covered broader topics such as safety regulations or certification requirements (e.g., for electronics). None of the companies had implemented VR or AR for training, though they expressed openness to adopting these technologies in the future. These findings highlight the need for a structured framework to systematically compare training strategies. By combining insights from the literature review with findings from company visits, we bridge the gap between the state-of-the-art and the state-of-practice.

4. FRAMEWORK FOR GUIDING TRAINING METHOD SELECTION

The results of this review provided valuable insights into the factors that influence the effectiveness of training methods in manufacturing, the criteria for selecting appropriate training methods, and how different training methods compare when applied to various task types. This section presents the findings, highlighting the contextual factors that drive the choice of training methods, the criteria used to scale and evaluate their effectiveness, and the comparative analysis of these methods across different training contexts.

4.1 Key Factors Influencing Training Effectiveness

Our analysis of the literature and expert feedback revealed that these contextual factors significantly affect the suitability and outcome of training programs. We introduce the factors below and propose the framework in Table 3.

Training Objectives Definition: The goals of a training program are guided by the complexity of skills required, safety requirements, certification and performance tracking needs. Tasks involving high risk, precision, and time pressure require advanced training solutions, such as immersive simulations, to develop complex skills in a controlled environment. Safety concerns may require the use of simulations for hazardous tasks, ensuring a risk-free learning experience (Doolani et al. (2020))). Furthermore, the ability to track performance in real time enhances training effectiveness by facilitating continuous feedback and progress monitoring (Roldán et al. (2019)).

Technological and Organizational Readiness: An organization's technological infrastructure, budget, and staff capabilities determine the feasibility of training methods. Low technological and infrastructure effort allows for easier implementation of digital solutions, while budget constraints may limit options for smaller enterprises (Doolani et al. (2020)). Technological proficiency among staff is also critical, as skilled personnel can seamlessly adopt advanced methods, while organizations with less experience may need to invest in preparatory training before adopting complex systems (Vélaz et al. (2014)).

Training Content and Audience: The structure and design of training content must accommodate various needs through visual, auditory or kinesthetic methods. Personalization of content, such as adapting hints or delivery styles, enhances learning outcomes. Consistency between

Table 2. Training metrics encountered in literature review

Group	Sub-elements
Training and Task Performance	Task Completion Time, Task Accuracy, Training Time, Long-term Skill Retention, Performance, Learning and Recall, Learning Process, Number of Hints Given, Voice Message Repetitions (Operator Confidence), Use-case Specific Performance Measures, Task Completion Time (man hours), Task Completion Time (Quantitative), Execution Time, Task Completion Time (Training Cycle Duration), Average Training Time, Assessment Scores (Quantitative), Performance Times, Number of Errors, Effectiveness, Efficiency (Task Completion Time)
Safety	Safety Violations, Operational Errors, Using Wrong Tools, Awkward Working Postures, Milestone Failures, Rework Time to Complete Task, Travel Distance to Complete Task
Cognitive Load & Engagement	Cognitive Load, Reaction Time, Perceived Engagement, Perceived Presence, Knowledge, Self-Efficacy, Task Difficulty, Feeling of Presence
Usability & Ease of Use	Usability, Ease of Learning, Enjoyment, Ease of Use, Satisfaction with Performance
Subjective Evaluation	Questionnaire (Qualitative), Subjective Evaluation, Risk Perception, Decision Making, Increased Productivity, Environmental Protection, Safety of Plant

all trainees ensures uniform knowledge and skills development. Furthermore, scalability and geographical flexibility are important for training large distributed teams, with AR and online solutions offering access to remote locations (Westerfield et al. (2015)).

Practical Constraints: Time flexibility, space requirements, and production impact are essential considerations when selecting training methods. Flexible schedules and low spatial dependencies, as provided by VR and AR, reduce disruptions to ongoing operations (Kaplan et al. (2021)). Training should also minimize interference with daily production tasks. Lastly, regulatory compliance must be addressed, as some industries have strict guidelines on training methods. Ensuring compliance with these regulations protects organizations from legal or safety issues.

By systematically addressing these factors, organizations can develop tailored training strategies that maximize effectiveness while balancing operational and resource constraints. The proposed framework supports decisions related to such constraints and requirements.

4.2 Rating the Framework Elements

We aim to avoid imposing strict ratings for each metric in the framework, as this may limit its adaptability to diverse contexts. Instead, we provide illustrative examples of how these metrics could be defined, drawing on insights from existing literature and practical use cases. To facilitate evaluation, we propose a 1-5 rating scale, where a higher value indicates greater suitability for the given context.

VR training is known for its high level of immersion and safety, making it ideal for complex and hazardous tasks; therefore, we could rate *Safety Requirements* and *Complexity of Skills* as 5. On the other hand, VR is not easily scalable given that each user needs a headset, therefore we would rate *Audience Scalability* and *Technological Effort* 1 or 2 depending on the requirements of the company. However, if a company already possesses the necessary VR equipment, scalability becomes less of a concern, and the technological effort required for implementation is reduced, potentially leading to higher ratings (e.g., 4). This variability illustrates why we do not apply strict, fixed ratings in the framework but instead consider company-specific factors.

AR training strikes a balance between the real and virtual worlds. It is effective for OJT and remote instruction, which could argue for a rating of 4 or 5 for *Geographical distribution*. On the other hand, same as for VR, certification is still a challenging aspect, although this might change in the future, when AR and VR gets more integrated in training routines.

Classroom training is a more traditional approach, known for its *Audience Scalability* opportunities and safety (*Safety Requirements*) (ratings of 4 or 5), but less flexible to personalization (e.g. rating of 3 since a teacher can adapt to the audience to a certain extent).

Expert help provides tailored instruction and support (rated 4 for *Personalization*), making it ideal for complex skills and problem-solving. It offers valuable insights and guidance. However, the *Consistency* of this kind of training is highly doubtable (e.g. rating 1) given that the experience and ways of working influences the knowledge transfer.

DWI methods offer flexibility and accessibility, scoring high in *Consistency* (rated 5) and Type of Instructions (video, text, audio,... - rated 4-5). However, real-time *Performance Tracking* can be more of a challenge (e.g. rating 2) compared to e.g. VR in which any type of interaction can be captured.

This framework provides a structure to enter baseline ratings for different training methods across elements such as *Technological Effort* and *Personnel Requirements*. Organizations then compare their own circumstances (like existing VR resources or the number of trainees) to these baseline values to determine the best-fit training method.

4.3 Utilizing the Framework in Practice

Imagine a manual assembly precision task tailored for 20 individuals in a factory. The framework becomes a valuable guide in recommending the most effective training methods. One might find that high-complexity tasks (*Complexity of Skills*) benefit greatly from AR or VR, offering immersive simulations and real-time feedback. Yet, scalability (*Audience Scalability*) matters less with a smaller audience size, making OJT or instructor-led sessions more practical. Meanwhile, when factors like Space Requirements and Impact on Daily Production pose constraints, more straightforward methods like DWI or text/video-based training might be preferable. When faced with such contradictory results, the framework remains flexible, allowing companies to determine which training method aspects have the greatest impact on their decision based on

Table 3. Proposed framework, consisting of all elements contributing to training methods

Theme	Training method aspect	Rating
Training Objectives Definition	**Complexity of Skills**: Risk, precision, time pressure	5: Supports complex skill development - 1: Supports basic skill development
	Safety Requirements: The training involves hazardous materials or environments	5: The training is completely safe - 1: Safety risks are the same as in the real job
	Certification: Possibility to obtain a certificate after training	Yes/No
	Performance Tracking: There is a need to measure progress and performance	5: Real-time and less effort - 1: Manual performance assessment at end of training
Technological and Organizational Readiness	**Technological Effort**: Effort to obtain and install equipment	5: Low effort - 1: Big effort
	Budget: The budget for initial setup and ongoing costs	5: Low costs - 1: High costs
	Personnel Requirements: The operating personnel is technologically adapted to use advanced training systems	5: Low requirements - 1: High requirements
Training Content and Audience	**Type of Instructions**: The training needs visual, auditory, or kinesthetic content for better understanding	5: Complex visualization capabilities - 1: Basic visualization capabilities)
	Personalization of Training: The training can be adapted to individual training needs (hints, more explanations, style)	5: High personalization - 1: Generic, no personalization
	Consistency: It is ensured that all the trainees get the same sequence of training	5: Very consistent - 1: Not consistent
	Audience Scalability: There is a need to train as many people as possible	5: Good scalability - 1: Bad scalability
Practical Constraints	**Time Flexibility**: How time-dynamic the training could be	5: High flexibility - 1: Low flexibility
	Space Requirements: Do you have the physical space needed for the training setup?	5: Any room/space is good - 1: Dedicated space
	Impact on the Daily Production: The training interferes with daily production, and some tasks need to be interrupted or delayed	5: No impact on production - 1: Big impact on production

their specific use case. In this example, the company can choose the option that best aligns with its preferences.

The framework may also recommend not one, but multiple training methods that perform similarly in certain aspects, depending on the requirements and use case. For instance, in a maintenance scenario, aspects like *Consistency*, *Safety*, *Personalization*, and *Type of Instructions* could be crucial. AR might score high on *Consistency* and *Type of Instructions* but low on *Safety* and *Personalization*, whereas Expert Help might exhibit the opposite pattern. Ultimately, selecting a training method is always an equation of many aspects, and there is no single ideal solution that fits all cases. Therefore, instead of enforcing a strict set of ratings for all aspects, we aim to offer a structured support system. This system can better guide the selection of training methods by helping users define which aspects are most relevant to their specific training needs without overlooking elements contributing to their decision.

5. DISCUSSION

The findings of this research highlight several important aspects of manufacturing training, particularly in relation to the diverse methods employed, their effectiveness, and the influencing contextual factors. This section discusses the broader implications of these findings and future research tracks.

The Need for a Training Recommendation Tool. A key insight from this study is the importance of a structured approach to selecting training methods. The proposed framework, outlined in our results, guides decision-makers in identifying suitable training approaches by considering factors such as company needs, technological readiness, training objectives, and task complexity. While the framework itself offers valuable guidance, it could be made more practical and actionable by developing a recommendation tool that leverages ratings for all training methods across different aspects. These ratings, provided on a 1–5 scale, would enable to recommend the most suitable training method when users define their specific training context based on the proposed aspects. Such a tool could operationalize the framework by offering tailored suggestions and reducing the guesswork involved in decision-making.

The Need for Secondary Validation. Besides the suggestion for a recommendation tool, secondary validation is crucial to prove the effectiveness in real-world scenarios. This involves empirical evaluation through pilot studies, where we involve training experts to validate the proposed framework. Such validation helps to improve the framework, ensuring it is practical and effective to be used in selecting the appropriate training methods.

Bridging the Gap Between Traditional and Digital Methods. Bridging the gap between traditional and digital methods is essential for creating hybrid training programs that leverage the strengths of both approaches instead of comparing them against each other. In literature, we often see a focus on one versus the other, such as AR or VR compared to OJT, but we believe complementary hybrid approaches represent the future. Hybrid training programs can combine e.g. VR or AR for foundational skill acquisition with OJT or mentorship for real-world application, blending immersive technology with expert insights (Freina and Ott (2015)).

Practical Implications for Industry. The practical implications of this research are significant for manufacturing companies looking to improve their training programs. The framework provides more structure to companies in choosing the best training methods based on their specific needs. It is designed as an ever-evolving tool that will adapt over time to reflect new developments in the training landscape, such as advancements in technology.

6. CONCLUSION

This research identified significant gaps in the literature regarding the comparison of current training methods in manufacturing. We proposed a decision-making framework to enhance the selection process for the most beneficial training methods in each situation. A key next step is to validate the framework with experts and operators to assess its relevance, usability, and acceptance. An operator-centered approach, aligned with Industry 5.0, ensures that training methods meet user needs and support effective adoption. We encourage other researchers to challenge and refine this framework, further advancing the field and enhancing the operator's role in training design. At the same time, improving the efficiency of manufacturing training remains a pressing priority, as cost and time constraints are crucial factors. By optimizing training methods and supporting informed decision-making, the proposed framework has the potential to make training programs more effective, adaptable, and resource-efficient, ultimately contributing to the broader goals of enhancing workforce capabilities and productivity.

ACKNOWLEDGEMENTS

This research is funded by EIT Manufacturing Doctoral School, and by Flanders Make through the project SKILLEDWORKFORCE.

REFERENCES

Bacca Acosta, J.L., Baldiris Navarro, S.M., Fabregat Gesa, R., Graf, S., et al. (2014). Augmented reality trends in education: a systematic review of research and applications. *Journal of Educational Technology and Society, 2014, vol. 17, núm. 4, p. 133-149.*

Brynjolfsson, E. and McAfee, A. (2014). *The second machine age: Work, progress, and prosperity in a time of brilliant technologies.* WW Norton & company.

Burke, L.A. and Hutchins, H.M. (2008). A study of best practices in training transfer and proposed model of transfer. *Human resource development quarterly*, 19(2), 107–128.

Daling, L.M. and Schlittmeier, S.J. (2024). Effects of augmented reality-, virtual reality-, and mixed reality–based training on objective performance measures and subjective evaluations in manual assembly tasks: a scoping review. *Human factors*, 66(2), 589–626.

Doolani, S., Owens, L., Wessels, C., and Makedon, F. (2020). VIS: An immersive virtual storytelling system for vocational training. *Appl. Sci. (Basel).*

Freina, L. and Ott, M. (2015). A literature review on immersive virtual reality in education: state of the art and perspectives. In *The international scientific conference elearning and software for education*, volume 1, 10–1007.

Huang, G., Qian, X., Wang, T., Patel, F., Sreeram, M., Cao, Y., Ramani, K., and Quinn, A.J. (2021). AdapTutAR: An adaptive tutoring system for machine tasks in augmented reality. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems.* ACM. doi:10.1145/3411764.3445283.

Ip, H.H. and Li, C. (2015). Virtual reality-based learning environments: Recent developments and ongoing challenges. In *Hybrid Learning: Innovation in Educational Practices: 8th International Conference, ICHL 2015, Wuhan, China, July 27-29, 2015, Proceedings 8*, 3–14. Springer.

Kaplan, A.D., Cruit, J., Endsley, M., Beers, S.M., Sawyer, B.D., and Hancock, P.A. (2021). The effects of virtual reality, augmented reality, and mixed reality as training enhancement methods: A meta-analysis. *Hum. Factors.*

Liu, X.W., Li, C.Y., Dang, S., Wang, W., Qu, J., Chen, T., and Wang, Q.L. (2022). Research on training effectiveness of professional maintenance personnel based on virtual reality and augmented reality technology. *Sustainability*, 14(21), 14351. doi:10.3390/su142114351.

Palmas, F., Labode, D., Plecher, D.A., and Klinker, G. (2019). Comparison of a gamified and non-gamified virtual reality training assembly task. In *2019 11th International Conference on Virtual Worlds and Games for Serious Applications (VS-Games).* IEEE. doi:10.1109/vs-games.2019.8864583.

Pimminger, S., Kurschl, W., Panholzer, L., and Schönböck, J. (2021). Exploring the learnability of assembly tasks using digital work instructions in a smart factory. *Procedia CIRP*, 104, 696–701. doi:https://doi.org/10.1016/j.procir.2021.11.117.

Psarommatis, F., May, G., and Azamfirei, V. (2023). The role of human factors in zero defect manufacturing: a study of training and workplace culture. In *IFIP International Conference on Advances in Production Management Systems*, 587–601. Springer.

Roldán, J.J., Crespo, E., Martín-Barrio, A., Peña-Tapia, E., and Barrientos, A. (2019). A training system for industry 4.0 operators in complex assemblies based on virtual reality and process mining. *Robot. Comput. Integr. Manuf.*

Schwab, K. (2017). *The fourth industrial revolution.* Crown Currency.

Vélaz, Y., Rodríguez Arce, J., Gutiérrez, T., Lozano-Rodero, A., and Suescun, A. (2014). The influence of interaction technology on the learning of assembly tasks using virtual reality. *J. Comput. Inf. Sci. Eng.*

Westerfield, G., Mitrovic, A., and Billinghurst, M. (2015). Intelligent augmented reality training for motherboard assembly. *Int. J. Artif. Intell. Educ.*

Wolfartsberger, J., Zimmermann, R., Obermeier, G., and Niedermayr, D. (2023). Analyzing the potential of virtual reality-supported training for industrial assembly tasks. *Computers in Industry*, 147, 103838. doi:https://doi.org/10.1016/j.compind.2022.103838.