White Paper

Work-Based Learning in Manufacturing Industry

A Sector-Based Meta-Analysis

Steffen Nixdorf, Fazel Ansari, Sebastian Schlund, Matthias Wolf, Maria Hulla, Maximilian Papa, Sebastian Bardy, Antonio Kreß, Jannik Rosemeyer

Imprint

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“We need a better understanding of which **learning approaches are actually being** used at workplaces.“

Univ.-Prof. Dipl.-Ing. Dr.techn.
Christian Ramsauer

Preface

Success-oriented industrial companies need to offer unique products and service bundles to their customers in a business environment that is characterized by supply disruptions, digitalization, automation, global warming, and skilled workforce shortage. These challenges force industrial companies to continuously reshape their value adding processes and, at the same time, new technologies are changing the way we work faster than ever before. Therefore, a continuous development of staff competence is the key enabler for wealth creation in Europe, especially in production-related areas. However, traditional forms of classroom education are no longer appropriate as a sole source of knowledge transfer to close arising skill gaps and enable employees to cope with technological changes on the job.

Vocational education and trainings are characterized by their authentic setting. For more than one decade, the International Association of Learning Factories (IALF) has been researching and designing learning systems (called learning factories), that provide such an authentic setting in small scale. In learning factories, learners analyze realistic processes, develop, and implement process improvements and deepen experience in the use of new technologies. This assists in educating excellently prepared students, qualified engineers and workers based on practical requirements in complex technical and organizational interrelationships of today’s industrial environments.

A success-story of the IALF are the working groups on various topics where scientific associates of different universities work together. Therefore, I appreciate and thank the working group of Work-Based Learning to foster synergies towards bringing new ideas into reality in learning environments. I am particularly pleased with the cross-university cooperation, which makes research on this scale possible at all.

We need a better understanding of which learning approaches are actually being used at workplaces. Until now, there was no comprehensive scientific overview of the distribution of types of Work-Based Learning in different industries. This white paper aims to close this gap through a systematic literature review. With its meta-analysis, it outlines the range of Work-Based Learning approaches employed in different industries for the first time. According to this, learning continues to mainly take place as off-the-job training, showing the need for an increased incorporation of learning factory-based approaches. At the same time, opportunities for interactive and collaborative settings are revealed.

Along with the trend toward technology-enhanced and hybrid-learning, there are countless opportunities for further research. I am curious to see new developments in Work-Based Learning in academics and industry that will enable the necessary transition processes for a sustainable industry.

Univ.-Prof. Dipl.-Ing. Dr.techn.
Christian Ramsauer
President of the International Association of Learning Factories (IALF)
Professor at Graz University of Technology

CHAPTER 1

Introduction and Motivation

1. Introduction and Motivation

The rapid pace of digital transformation in manufacturing raises societal attentions to new ways of vocational education and on-the-job training. This is rooted in the fundamental demand of manufacturing enterprises for organization-wide competence development and planning in particular for (de-)skilling, re-/upskilling of workforces, and in turn recruiting competent workforce of the future. During the COVID-19 pandemic, new ways of working have been emerging and could achieve certain levels of acceptance by industries and individuals. At the same time, new challenges are revealed concerning accelerated hybridization of work, digital and blended collaboration and eventually extended digital divide between white and blue collars. Notably, the latter did not benefit from advantages of remote work but had to deal with many challenges in presence. These challenges compound the demand on digital competences and raise attentions to effective measures for empowering human workforces on digitalized and technology-rich workplaces. In order to cope with the pace of change, vocational education institutions providing professional training programs for manufacturing enterprises need to critically rethink the as-is state, identify gaps based on new demands and thus improving educational concepts, models, and processes as well as underlying methods, tools and related infrastructure.

Despite the increasing industrial demands and urgency on innovative Work-Based Learning (WBL) and professional training, yet the potentials for introducing new, adapted, and tailored-made solutions remains unexhausted. WBL merges theory and practice. It emphasizes that the workspace offers many opportunities for learning, i.e., obtaining knowledge, skills, and competences by experience. This is mainly due to its realistic, situated, complex and problem-oriented characters.

Considering the learning venue and workplace, WBL can be categorized into three types[1] with certain coverage to the workplace (cf. Figure 1):

- **Work-oriented learning**, where learning mainly takes place in institutional settings such as schools, training centers or universities. Work processes, tasks and organization are simulated, e.g., e-learning, learning factories, off-the-job training courses.
- **Work-connected learning**, where learning venue and workplace are separated. Spatial and organizational connection between learning environment and workspace is present, e.g., learning at digital or physical twin next to the workplace, internships.
- **Work-integrated learning**, where learning venue and workplace are identical. The actual learning takes place at the workplace or in the work process, e.g., on-the-job training, traditional apprenticeship.

[1] Dehnbostel, P., Schröder, T. (2017). Work-based and Work-related Learning – Models and Learning Concepts, TVET@Asia. 1–16.

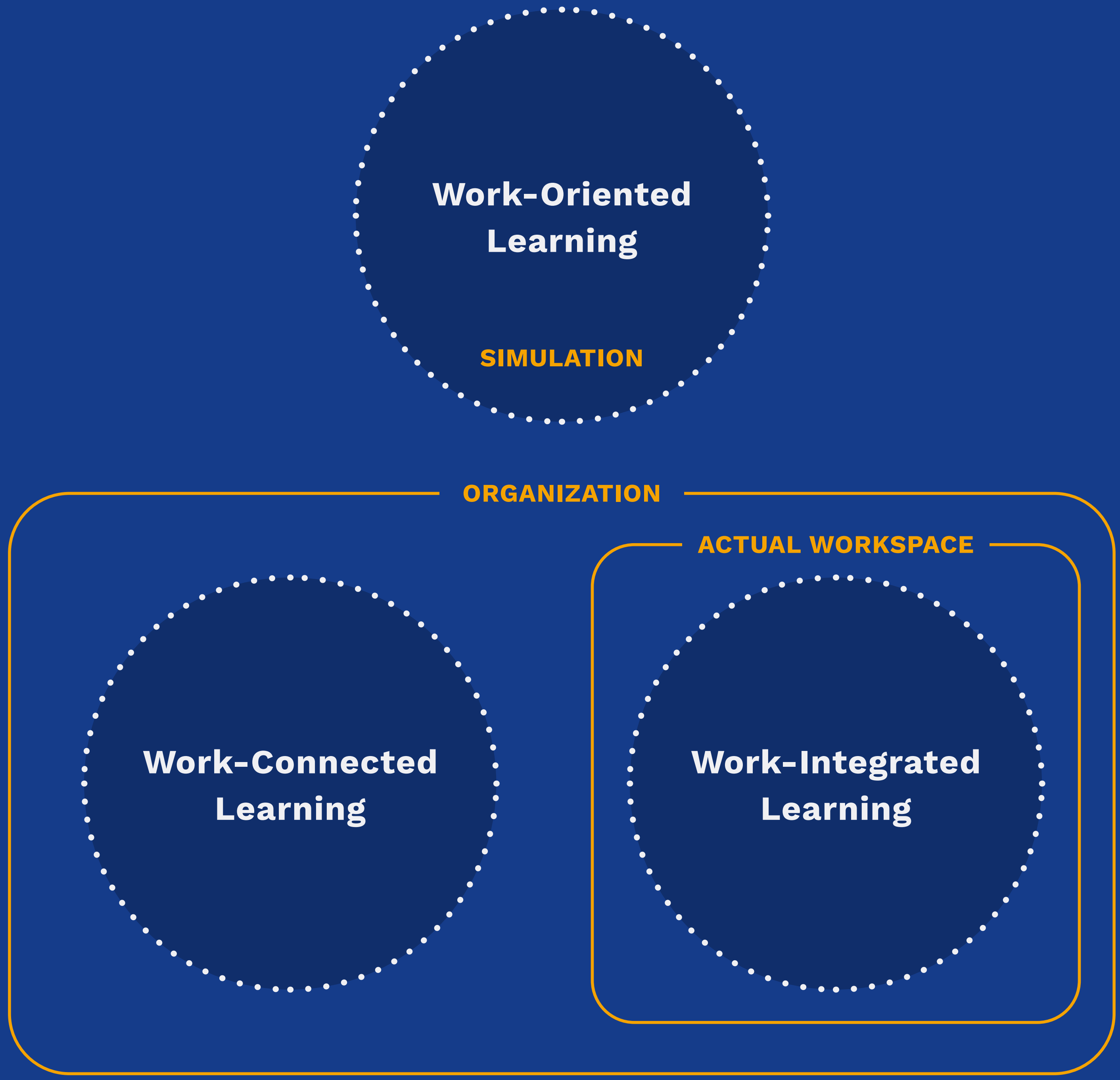

Figure 1. Concept of Work-Based Learning inspired by Dehnbostel & Schröder (2017)

The scope of WBL is extended through incorporation of new ways of technology-enhanced learning such as hybrid and blended learning, which raise new learning opportunities for both trainees and trainers by combining online and presence learning. Further, educational institutions and manufacturing enterprises could find new alignments towards filling the existing gaps in WBL programs and providing new learning opportunities to (future) workforces.

There are several ways and in fact brands for realizing a WBL environment, such as but not limited to learning- and teaching factories, makerspaces and industrial fabrication laboratories known as fablabs. A learning factory is a notable example of WBL environment, where processes and technologies are based on a real industrial site, which allows a direct approach to product creation and operation management process. Learning factories are authentic factory environments or simulations thereof that are used for educational, training and/or research purposes[2]. According to Abele et al. (2019), definitions about learning factories follow either of the following notions:

- In a narrow sense, a learning factory is specified by authentic manufacturing practice, including processes, physical value chains and products, comprising technical as well as organizational aspects. Furthermore, a dedicated didactical concept enables learning through teaching, training, and research.

- In a broader sense, learning environments defined above may also resemble virtual value chains, service products (instead of physical), and didactical concepts, which may allow offsite learning, such as remote learning.

Learning and teaching factories are based on a didactical concept emphasizing experimental and problem-based learning. The continuous improvement philosophy is facilitated by own actions and interactive involvement of the participants[3].

Exploring industrial demands on diverse and novel WBL approaches, this white paper is to deepen the insights by conducting a sector-based meta-analysis to identify state-of-the-art WBL approaches. In particular, it aims at extending the scope of WBL research to the entire manufacturing sectors to a) create an overview of As-Is state, b) find hidden areas as well as emerging trends, and c) connect to similar and possibly even complementary WBL communities. To accomplish the aforementioned objectives, Statistical Classification of Economic Activities in the European Community (NACE)[4] is used as a reference. NACE uses hierarchical digits of codes in four levels to classify economic activities in all European states. It aggregates "Manufacturing" sector under Level 1 (Code C), which is composed of 13 categories in Level 2 (CA-CM) as sketched in Figure 2 below[5].

Notably, the main hypothesis of this research is that there is a misbalance and missing link between theory and practice in WBL approaches in diverse industrial sectors. To the best of knowledge of the authors, there is no specific study examining the state of the art in WBL in relation to the entire manufacturing sectors. Therefore, the present white paper is primarily to pave the ground and conduct the sector-based meta-analysis of the accumulated literature. To purse this line of research, a database is established (cf. Appendix I), which will be provided to all scholars and interested researchers. Furthermore, similarities and differences are critically reflected and potential future perspectives for WBL in manufacturing are suggested.

In the followings, Section 2 provides more insights to the methodology of the literature survey and the related metadata. Section 3 elaborates on the initial findings supported by interpretations. Finally, Section 4 discusses the significance of the sector-based meta-analysis and provides the pathways for future research.

[2] Abele, E., Metternich, J., Tisch, M. (2019). Learning Factories: Concepts, Guidelines, Best-Practice Examples. Springer, Cham.

[3] Abele, E., Metternich, J., Tisch, M. (2019). Learning Factories: Concepts, Guidelines, Best-Practice Examples. Springer, Cham.

[4] NACE stands for the French term "nomenclature statistique des activités économiques dans la Communauté européenne".

[5] NACE Website: https://nacev2.com/en/activity/manufacturing

Figure 2. Classification of Manufacturing Industry according to NACE

CHAPTER 2

Methodology of Literature Survey and Metadata

2. Methodology of Literature Survey and Metadata

Sector Keywords

CA	“food”, “grocery”, “tobacco”, “smok*”, “beverage”, “drink”, “food sector”, “beverage sector”, “tobacco sector”, “drink sector”
CB	“textile*”, “garment”, “apparel”, “clothing”, “fashion”, “leather”
CC	“wood”, “lumber”, “timber”, “carpenter”, “wood manufact*”, “furiture”, “paper”, “pulp and paper”, “print*”
CD	‘”coke”’, “cole mining”, “mining”, “petroleum”, “petrochemical”, “oil and gas”
CE	“chemical”, “paints”, “coating”
CF	“botanical”, “pharmaceutical”, “medicinal”, “chemical”
CG	“rubber”, “plastics”, “non-metallic”, “mineral”, “glass”, “cement”, “concrete”
CH	“metal*”, “iron”, “steel”, “weapon”, “ammunition”
CI	“computer”, “electronic*”, “electro*”
CJ	“cable”, “wire*”, “battery”, “accumulator”, “electric”
CK	“engine”, “machinery”, “machine tool”, “hand tool*”
CL	“naval”, “automotive”, “railway”, “aeropspace”, “transport* equipment”
CM	“maintenance”, “repair”, “installation”

AND

Manufacturing Keywords

“product*”
“industry”
“sector”
“manufact*”

AND

Training Keywords

“vocational training”
“work-based learning”
“work-oriented learning”
“work-connected learning”
“work-integrated learning”
“professional training”
“on-the-job training”
“work* learning”
“practice-oriented learning”
“practitioner learning”

Figure 3. Construction of Search String

The results presented in this white paper have been obtained by a systematic literature review. The systematic search was conducted in SCOPUS[16]. To construct the search strings, initially, three sets of keywords were used, specifying sector, manufacturing, and training keywords (cf. Figure 3).

Each manufacturing sector, distinct by NACE code (aggregated edition) was searched separately with sector-specific keywords, which represent the products of the sectors (cf. Sector Keywords, Figure 3).
A set of manufacturing-related keywords for tailoring search results to manufacturing was defined (cf. Manufacturing Keywords). In addition, a set of training-related keywords was used in order to elicit publications, which contribute to training and learning (cf. Training Keywords). Title, abstract, and keywords of papers was searched only. Basically, each of the three mentioned sets of keywords needed to have at least one match to be included, respecting the following search string: TITLE-ABS-KEY (([Sector Keywords] AND [Manufacturing Keywords]) AND ([Training Keywords])).

This search resulted in 2,416 publications including conference papers and journal articles with diverse quality.
The search results have been refined focusing on language and quality criteria, i.e., i) English publication and ii) journal articles and conference proceedings, based on peer reviewed evaluation process. Additionally, an explorative refinement of the search by screening of titles and abstracts was conducted. Only thematically relevant publications, namely publications concerning learning of current manufacturing workforce were included.

[6] Scopus is Elsevier’s abstract and citation database. Link: https://www.scopus.com

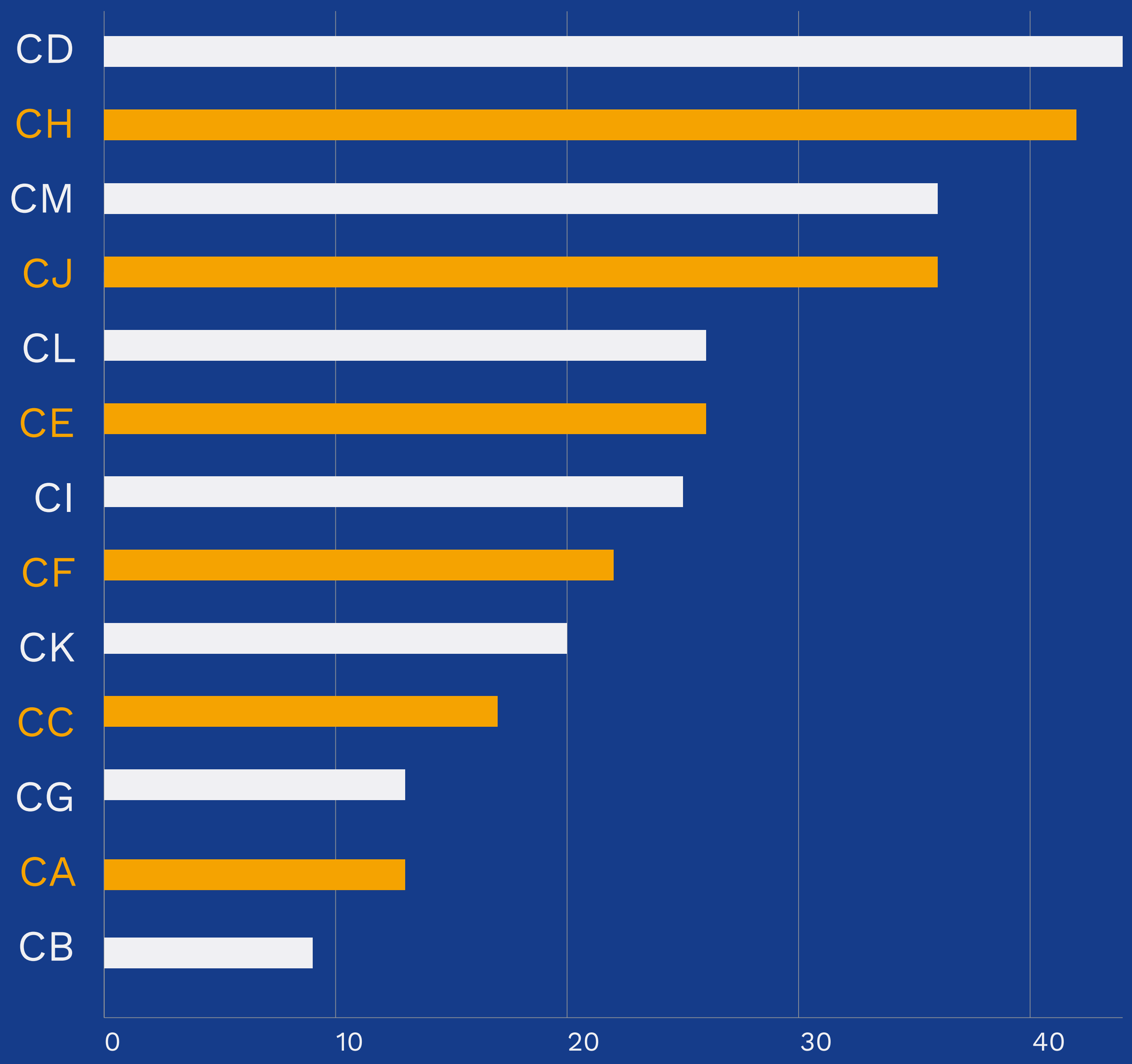

Figure 4. Publications relevant to WBL per sector

Most of the publications were excluded because of their lack of specification towards manufacturing (approx. 70%). Importantly, the search strings for CC (i.e., wood, furniture, paper) and CI (i.e., computer, electronics) obtained significantly more results than the others. For CC, this is due to the keyword "paper", which unsurprisingly resulted in many more hits. For CI, it is the connection between two keywords, namely "computer" and "learning", thus many publications on artificial intelligence and machine learning were excluded in the refinement (approx. 90% of CI's total). Once the results were refined, 271 publications remained, as depicted in Figure 4. Each paper was assigned to a type of WBL, possibly, if more are applicable, to more than one type. Moreover, some publications were also applicable to more than one industry sector. An analysis of the refined publications revealed a trend in publications per year, which is increasing over time (cf. yellow trend line in Figure 5). It needs to be mentioned that data for 2022 is incomplete since the year 2022 was only considered until February for this white paper. Accordingly, the year 2022, while included in the review, is excluded from Figure 5 in order to avoid any interference with the trend line.

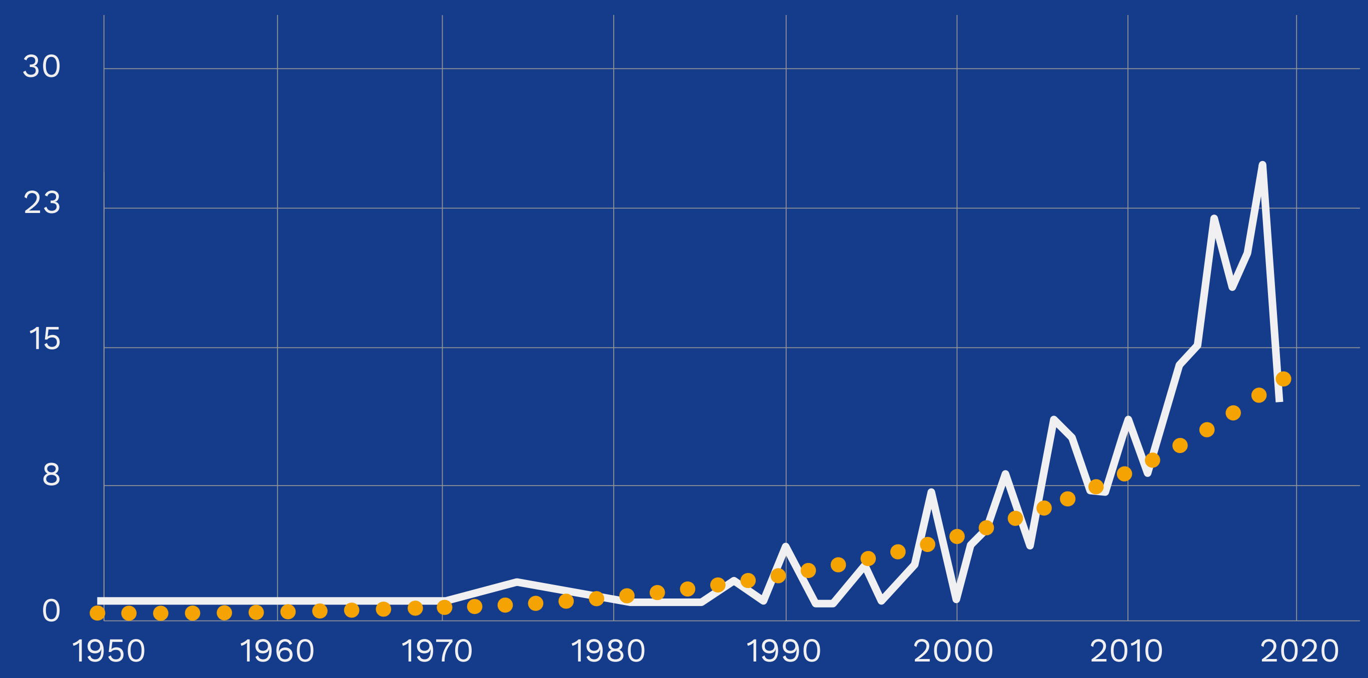

Figure 5. Trend of number of WBL publications per year in manufacturing

CHAPTER 3

Initial Findings and Interpretation

3. Initial Findings and Interpretations

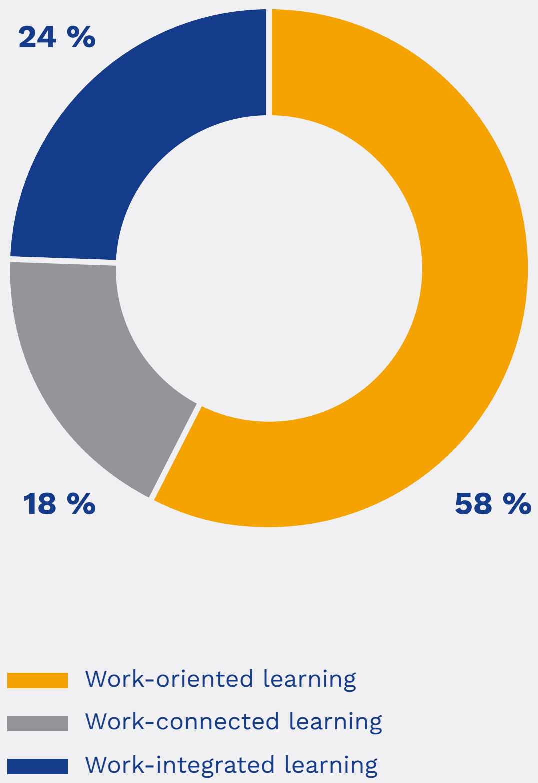

Figure 6.
Distribution of types of WBL in manufacturing

After passing quality checks, 271 papers, were considered for the quantitative analysis of WBL in manufacturing sectors. The vast majority (189; 58%) are dedicated to work-oriented learning. Work-connected learning (60; 18%) and work-integrated learning (80; 24%) are both underrepresented, as depicted in Figure 6.

Work-oriented learning features various didactical approaches. Traditionally, work-oriented learning takes place in institutional settings such as schools, training centers or universities. There, work processes, tasks and organization are simulated, such as in production schools and training courses. Work-oriented learning comprises most traditional lifelong learning approaches, including VET[7] schools and off-the-job training, but also novel approaches, such as E-learning. E-learning has been recently gaining impact on professional training in manufacturing, e.g., maintenance[8]. The self-paced nature of E-learning benefits learning and training, thus possibly promoting further growth into work-oriented learning. More advanced techniques such as virtual reality-based trainings[9] are also picking up attention in the realm of work-oriented learning and learning factories.

Work-connected learning distinguishes between learning venue and workplace, while spatial and organizational connection between learning environment and workspace is present, e.g., via learning stations, internships. Interestingly, work-connected learning methods are rather scarce in the manufacturing industry. Just 18% of literature presents learning venues that are connected to the workplace, but not integrated. This might be due to the ambiguity and multiplicity of the applied terms in literature of WBL in manufacturing, which reveals the need for a standard glossary, or the niche opportunities to realize such trainings. From practical perspective, however, it can be related to the vast space requirements for training facilities. Hence, work-connected learning is rare as training facilities are mostly unproductive by design, solely designed for fostering learning rather than productive outputs. Further, it is argued, that many of the existing work-connected learning measures in manufacturing companies are not subject to accessible publications. Therefore, the existing body of knowledge lacks insight into the state of the practice, such as internal learning factories, e.g., Kärcher Learning Factory[10], BMW VPS Learning Factory[11], Knapp Service Factory[12].

Work-integrated learning combines training at the workplace. Learning venue and workplace are identical, thus most of the learning by doing approaches, such as on-the-job training and traditional apprenticeship are dedicated to work-integrated learning. Especially, in manufacturing, which has been traditionally defined by manual tasks, tackling job-related problems hands-on to obtain skills and competences is widely acknowledged. Furthermore, work-integrated learning has potential to further grow by deployment of intelligent machines into collaborative work systems.[13]

The meta-analysis of WBL in manufacturing sectors shows differences by wide margins. As depicted in Figure 4, WBL-related literature is evenly distributed between all manufacturing sectors. CD (i.e., coke, oil and gas), CH (i.e., metal products), CJ (i.e., electrical equipment), and CM (i.e., maintenance) have the most publications relevant to WBL, while CA (i.e., food and beverage), CB (i.e., textile, clothing), and CG (i.e., rubber, plastics) have the least. Without any qualitative analysis of the publications, the small disparity may be due to the size of the sector (number of workers) and their location. For instance, WBL and scientific publishing in general is prevalent in developed countries, in contrast to developing or underdeveloped countries. Thus, manufacturing sectors associated to developed countries may have higher numbers of publications.

Analysis of types of WBL addressed within each manufacturing sector reveals considerable differences. As depicted below, CD (i.e., coke, oil and gas), CF (i.e., pharmaceuticals), CG (i.e., rubber, plastics), CH (i.e., metal products), and CL (i.e., computer, electronic) mimic the overall assessment of types of WBL in manufacturing (cf. Figure 6), thus being close the average distribution. The share of work-oriented learning has been considerably increased for CB (i.e., textiles, clothing), CC (i.e., wood, furniture, paper), CI (i.e., computer, electronics), CK (i.e., machinery, equipment), and CM (i.e., maintenance) - between 64% to 100%. CA (i.e., food and beverage) and CE (i.e., chemicals) have significantly higher ratios of work-integrated and work-connected learning.

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[7] According to Eurostat: “Vocational education and training, abbreviated as VET, sometimes simply called vocational training, is the training in skills and teaching of knowledge related to a specific trade, occupation or vocation in which the student or employee wishes to participate”. Link: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Vocational_education_and_training_(VET)

[8] Papathanassiou, N., Emmanouilidis, C. (2010). e-Learning in Maintenance Management Training and Competence Assessment: Development and Demonstration. In: Kiritsis, D., Emmanouilidis, C., Koronios, A., Mathew, J. (eds) Engineering Asset Lifecycle Management. Springer, London. https://doi.org/10.1007/978-0-85729-320-6_101.

[9] Chakraborty, P. R., Bise, C. J. (2000). A virtual-reality-based model for task-training of equipment operators in the mining industry. Mineral resources engineering, 9(04), 437-449.

[10] Thomar, W. (2015). Kaerchers Global Lean Academy Approach: Incentive talk (industry), Bochum, Germany.

[11] Herrmann, S., Städel, T. (2014). Learn and Experience VPS in the BMW Learning Factory. 4th Conference on Learning Factories, Stockholm, Sweden, 1–18.

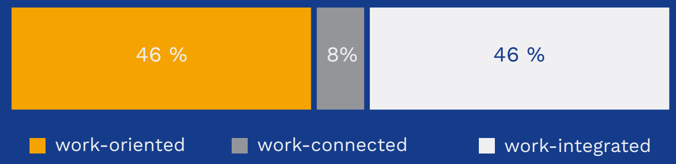
[12] Sadaj, E. A., Hulla, M., Ramsauer, C. (2020). Design approach for a learning factory to train services. Procedia Manufacturing, 45, 60-65.

[13] Nixdorf, S., Ansari, F., Sihn, W. (2021). Work-Based Learning in Smart Manufacturing: Current State and Future Perspectives. Proceedings of the Conference on Learning Factories (CLF) 2021.

Manufacturing of food products, beverages and tobacco products (CA)

mainly divides into work-oriented and work-integrated learning (each 46%), while work-connected learning is almost neglectable. This is a rather traditional distribution, which fits the sector's reputation. The distribution is mainly divided between work-oriented learning in VET schools and off-the-job training, as well as work-integrated learning as practiced in apprenticeships. An adoption of learning factories in mobile form is known[14].

Figure 7.
Distribution of WBL in CA (e.g., food & beverages)



Manufacturing of textiles, apparel, leather and related products (CB)

is even limited to work-oriented learning entirely. The lowest number of publications (9) available could explain this. Still, potentials for promoting work-connected and work-oriented learning are evident. Nevertheless, the textile industry supports the Textile Learning Factory 4.0 located in Germany[15], which offers trainings in work-oriented learning environments aiming at digitalization in the industry. Therefore, traditional VET schools and professional schools are complemented by advanced training approaches.

Figure 8.
Distribution of WBL in CB (e.g., textile, clothing)

Manufacturing of wood and paper products, and printing (CC)

is comparable to CA (i.e., food and beverage) in not reporting papers in relation to work-connected learning as well as the traditional reputation of the sector. It is assumed, that either of work-oriented and work-integrated learning mostly consist of traditional training approaches.

Figure 9.
Distribution of WBL in in CC (e.g., wood, furniture, paper)

[14] McHauser, L., Schmitz, C., Hammer, M. (2020). Model-Factory-In-A-Box: A portable solution that brings the complexity of a real factory and all the benefits of experiential-learning environments directly to learners in industry. Procedia Manufacturing, 45, 246-252.

[15] Küsters, D., Praß, N., Gloy, Y.-S. (2017). Textile learning factory 4.0—Preparing Germany's textile industry for the digital future. Procedia Manufacturing, 9, 214–221.

Manufacturing of coke, and refined petroleum products (CD)

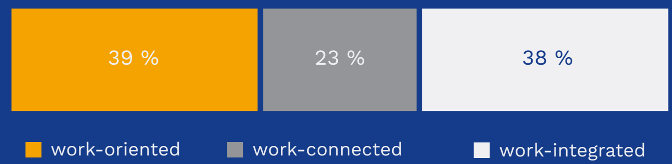
follows the overall distribution in manufacturing, while offering rather high levels of work-connected learning. In mining and petrochemical industry, including following processing, space requirements for work-connected learning systems can be met relatively easy. In addition, given the characteristics of the sector's business, namely markets consisting of relatively few but big companies which operate globally while controlling their respective regional business, as well as the concerning political sensitivity of the business for the last few decades, the lack of work-oriented training opportunities could be explained.

Figure 10.
Distribution of WBL in CD (e.g., coke, oil & gas)

Manufacturing of chemicals and chemical products (CE)

has even higher ratios regarding work-connected and work-integrated learning than CD (i.e., coke, oil and gas), which presumably follows similar considerations. Process technology is tailored to the manufacturers needs and in general highly specific, thus learning at work, either at the workplace or in simulated work systems is preferred.

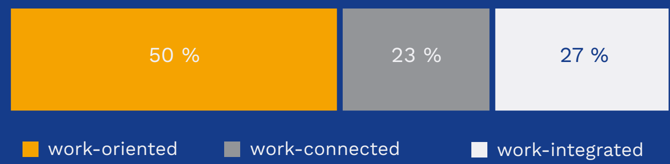
Figure 11.
Distribution of WBL in CE (e.g., chemicals, paints)



Manufacturing of pharmaceuticals, medicinal chemical and botanical products (CF)

have around 50% of publications dedicated to trainings at the workplace or connected to it, which is assumed to result from highly specific processing and sensitive production in this sector.

Figure 12.
Distribution of WBL in CF (e.g., pharmaceuticals)



Manufacturing of rubber and plastics products, and other non-metallic mineral products (CG)

does most of the training either connected or oriented to the workplace. Work-integrated learning is rare. In general, CG is one of the sectors with the fewest publications (13), and as such percentages may not be representative.

Figure 13.
Distribution of WBL in CG (e.g., rubber, plastics)

Manufacturing of basic metals and fabricated metal products, except machinery and equipment (CH)

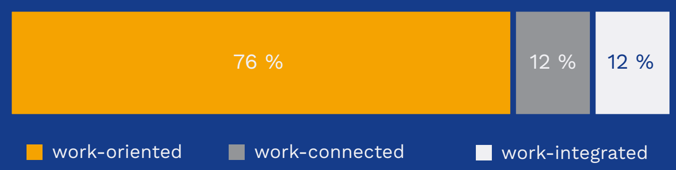
has almost identical ratios as the overall distribution in manufacturing (cf. Figure 6), also affected by the high number of publications at hand.

Figure 14.
Distribution of WBL in CH (e.g., metal products)

Manufacturing of computer, electronic and optical products (CI)

is assumed to rely heavily on work-oriented learning (76%), thus traditional VET. Further, the sector itself may also be more apt for E-learning as it has been subject to rather fast technological advance in recent decades.

Figure 15.
Distribution of WBL in CI (e.g., computer, electronic)



Manufacturing of electrical equipment (CJ)

mimics the overall average well (cf. Figure 6), which may be related to the significant size of the sector and its intrinsic differences related to the wide sector scope.

Figure 16.
Distribution of WBL in CJ (e.g., electrical equipment)

Manufacturing of machinery and equipment n.e.c. (CK)

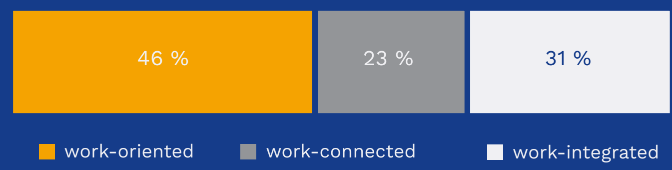
facilitates mostly work-oriented learning, whether this may be traditional VET, professional schools or even E-learning. Similar to CJ, this sector's distribution is closely following the overall averages (cf. Figure 6)

Figure 17.
Distribution of WBL in CK (e.g., machinery, equipment)

Manufacturing of transport equipment (CL)

offer rather high ratios in work-connected and work-integrated learning. This is assumed to be due to the size of components of transport equipment, e.g., automotive, railway, aerospace, naval. In this way, trainees are needed to learn in real production environments, where access to the product is granted.

Figure 18.
Distribution of WBL in CL (e.g., transport equipment)



Other manufacturing, and repair and installation of machinery and equipment (CM)

is in contrast with the other sectors not defined by a product, rather than services, e.g., maintenance and installation of equipment. However, the ratios do not differ widely from the other sectors. Still, work-oriented learning and work-integrated learning are prevalent. Training service personnel on simulated environments separated from actual workplaces, especially if the object to be repaired is specified, is considered an effective training strategy, directly complementing work-oriented learning.

Figure 19.
Distribution of WBL in CM (e.g., maintenance)

CHAPTER 4

Significance of Sector-Based Research and Outlook

4. Significance of Sector-Based Research and Outlook

This white paper focuses on the analysis of scientific literatures to identify the as-is state of WBL in diverse industrial sectors. It revealed the major lack in the literature of engineering education, including the learning factory community, on establishing a common ground for addressing training demands of manufacturing industries. The sector-based meta-analysis has already confirmed the initial hypothesis that there is a misbalance regarding implementation of WBL approaches in diverse manufacturing sectors. It opens the discussion to identify sector-specific reasons and boundary conditions as well as barriers to efficient, target-oriented and plausible implementation of WBL. Besides, the study raises questions about aggregative analysis of WBL approaches across all industrial sectors as the skill mismatch and also empowering workforces are today's cross-industry challenges. Here, the present meta-analysis comes into its limit and further insights from diverse sectors, i.e., voice of industries, need to be gained.

Learning factories are usually aimed at a specific purpose, whether it is education, training, or research, which define, inter alia, target groups, learning subjects, and research topics, rather than involved industry sector. However, learning factories can be specifically tailored to an industry[16]. According to Abele et al. (2019) these specifications are relatively rare, e.g., automotive[17], pharmaceutical[18], textile[19]. The scope of applicable industry sectors in the learning factory morphology of Abele et al. (2019) can be extended i) to align with the NACE classification, and ii) to go beyond the manufacturing industry, by considering other high potential sectors e.g., banking, insurance, IT. Due to processes and products being specific to particular industries, further research of existing learning factories and their dedicated industry sectors is encouraged in order to close the gap in WBL.

The study of 310 selected papers revealed certain levels of development and maturity of employed WBL approaches. However, further qualitative and in-depth study is required to assess the quality of reported WBL approaches. It is also essentially required to expand the scope of the study by incorporating further scientific databases, multiple languages and also by building and using a multiple combinations of keywords including synonyms in the search strings. In addition, desktop research, market analysis and interviews with training providers and institutions could facilitate building up a complementary channel of information to describe the underlying reasons and factors shaping the current state of WBL in diverse industrial sectors.

The sector-based meta-analysis also raised some yet unanswered questions regarding demarcating and classification of WBL approaches. In this white paper, work-oriented, -connected and –integrated approaches are distinguished based on the association between venue of work and learning. Due to the emergence of digital learning and new ways of on-the-job and remote learning in technology-rich workplaces, there is a demand to rethink this categorization and reconsider the boarders for demarcating work-oriented and work-connected learning. This reveals the demands on “standardization of terminologies in WBL” and also establishing institutional link between engineering education and pedagogical as well as didactical communities.

[16] Abele, E., Metternich, J., Tisch, M. (2019). Learning Factories: Concepts, Guidelines, Best-Practice Examples. Springer, Cham.

[17] Oberthuer, C. (2013). Integration of process simulations into the CIP of energy efficiency at daimler trucks. In G. Reinhart, P. Schnellbach, C. Hilgert, & S L. Frank (Eds.), 3rd Conference on Learning Factories, Munich, May 7th, 2013 (pp. 38–47). Augsburg.

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Focusing on three major types of WBL, the study revealed the need for a closer look at the work-connected learning as an underrepresented WBL approach in the studied papers. Further in-depth studies are required to identify the reasons, especially examining whether the practical settings or ambiguity of terms led to such a result.

In the context of WBL, especially in work-oriented learning, technology-enhanced and hybrid-learning approaches are the most notable emerging trends. This is due to the effectiveness and self-pace nature of these approaches, which could facilitate off-the-job training. However, in the work-connected and –integrated learning, due to the interface and merging of learning and working venues respectively, learning assistance and AI-enhanced digital assistance systems seem to be preferably implemented. However, scientific and practical evidence are required to confirm this hypothesis. Therefore, characterization of technology-enhanced learning and learning assistance systems should be a subject of further research to identify plausibility criteria for incorporating those digital solutions in WBL linked to individual and group learning success.

Not forgetting that human-AI teaming is an emerging area of research, the scope of WBL should be also extended towards new ways of learning in collaborative work systems that facilitate WBL. A notable example is reciprocal learning[20], which focuses on augmenting human and AI learning opportunities in interactive and collaborative settings.

Finally, yet importantly, this study addresses academics and scholars in WBL who majorly benefits from its findings. Nevertheless, manufacturing industries and professional training providers are indirectly addressed. To pursue this line of research in WBL, it is strongly recommended to consider sector-based analysis of WBL approaches from both theoretical and practical perspectives involving manufacturing and educational scholars as well as manufacturing professionals and human resource experts. Hence, both theory and practice can benefit from joint research.

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Appendix: Literature Database

Literature Database can be accessed via TU Wien Repositorium under following DOI:

DOI: https://doi.org/10.48436/tqtym-nyh26

About the IALF Working Group

The International Association of Learning Factories (IALF) is an academic society involving professors, researchers and faculty members from technical universities and universities of applied sciences as well as research centres. IALF stands in the focal point of Work-Based Learning (WBL), providing a unique opportunity to create synergy between research and education towards fulfilling industrial demands. Over the past years, IALF community strives to integrate, evaluate, and further develop latest research findings and prototypes in associated learning factories and so ensure that trainees and students get in touch with the newest technological developments. Thus, they obtain industry demanded competences and skills.

Under the flagship of Work-based Learning, a group of IALF researchers from TU Wien, TU Graz and TU Darmstadt has started to pave the ground and engaged in initiating a database for systematic literature survey to turn light into WBL approaches designed for, implemented, and integrated in specific manufacturing sectors. The team who contributed to this white paper are briefly introduced below.

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Work-Based Learning in Manufacturing Industry

A Sector-Based Meta-Analysis