In: 13th Conference on Learning Factories, CLF 2023
9-11 May 2023, Reutlingen, Germany
DOI:10.2139/ssrn.4471445

13th Conference on Learning Factories, CLF 2023

The Learning Factory through the Sustainability Lens

Milisavljevic-Syed, J.[a]*, Afy-Shararah, M.[a], Sahin, O.[a], Salonitis, K.[a]

Sustainable Manufacturing Systems Centre (SMSC), School of Aerospace,Transport and Manufacturing, Cranfield University, College Road, Bedford, MK43 0AL, United Kingdom

Abstract

Manufacturing organizations are facing increasing global pressures to be more digitalized, sustainable, and lean. Whereas the manufacturing industry is facing a shortage of demanding competencies of Industry 4.0., because the talent pool is either dry or the knowledge related to such skills is still not clearly formulated. Learning factories, through their triangular depth of education, research, and training, have been seen by many researchers in recent years as suitable environments to address these gaps in knowledge and skills. Although it is very useful for academia and industry alike, not much has been found on how to develop a learning factory. In this paper, the authors propose a new morphology and shed light on the sustainability that should be addressed when designing or reconfiguring learning factories. They provide existing limitations and future challenges and questions as research opportunities that must be addressed to further advance this learning environment.

Peer Review statement: Peer-review under responsibility of the scientific committee of the 13th Conference on Learning Factories 2023.

Keywords: learning factory; morphology; sustainability; competencies development

1. Introduction

One of the problems of Industry 4.0 (I4.0) is that its sole focus is to improve the efficiency of the process, which unintentionally ignores the social and environmental impact resulting from the optimization of the processes. Moreover, recent events such as the pandemic, the war in Ukraine, and the blockage of the Suez Canal have further emphasized the importance of resilience at various levels to safeguard sustainability. Industry 5.0 (I5.0) is a forethoughtful concept on the future of the industry towards a human-centric, sustainable, and resilient manufacturing system, however, its elements are weakly addressed in the current literature on learning factories. This paper sets out to address this gap by mapping the existing learning factories (LF) against key perspectives to identify the gap that accounts for a green and social industrial strategy.

2. Research Design and Methodology

The authors used a three-step methodology: systematic literature review, descriptive mental model, and morphology analysis. In Section 3, relevant articles were found by searching seven databases using specific keywords. In Section 4.1, a descriptive mental model was used to map out the identified learning factories, and in Section 4.2, a new morphology ingredient on sustainability was proposed for designing or reconfiguring such factories. The paper concludes by providing existing limitations and future challenges and questions as research opportunities.

3. Literature Review

* Corresponding author. Tel.: +44(0) 1234 758533
E-mail address: j.milisavljevicsyed@cranfield.ac.uk

The manufacturing sector contributes to economic growth and makes it possible for technology to advance and extend to other industries [1, 2]. Industry 4.0 (I4.0), aims transformation of traditional industrial manufacturing via digitalization and utilizing new technologies such as the Internet of Things, Cyber-Physical Systems, etc. [3, 4]. The European Commission announced Industry 5.0 (I5.0), which focuses on sustainability, human centricity, and resilience, and places the well-being of industry workers at the core of the production process in contrast to I4.0, which focused on boosting industrial efficiency and flexibility [5-7]. Industry requires a new generation of skilled workers who have proficiency in digital technologies and production automation at all levels [8].

Small and medium-sized enterprises (SMEs) are the foundation of the manufacturing sector [9]. To sustain economic growth in a region, SMEs should adopt I4.0 technologies, but there are many barriers and challenges that SMEs must overcome first, such as lack of investment [10] and security risks [11]. One of the biggest challenges which SMEs confront is the workforce not having skills and competencies for I4.0 [12-15]. Similarly, according to the I5.0 initiative industrial workers should continue to upskill and reskill to advance their careers and maintain a work-life balance [7]. However, the development of these competencies has not been sufficiently aided by traditional teaching methods [16].

Policy changes in education and training should be made to reflect the demands and development of the digital era. This arrangement needs to be made in vocational schools [17, 18] as well as higher education [19]. New teaching methods are being developed to train and educate the workforce that will have the necessary competencies to keep up with digitalization. Pedagogically, a learning factory (LF) is one of the best tools to use at the intersection of academic and industrial settings [18]. Learning factories realize work-based learning [20] and adopt the learning-centered approach as opposed to the traditional, one-way teaching-centered approach [16]. In LF, a wide range of learning theories are used, including lifelong learning, learning by doing, constructivist didactics, action-oriented learning, game-based learning, and simulation games [21]. LFs, which are characterized as an ideal replica of real production environments [22], serve as both hands-on and theoretical training tools for students and employees as well as facilitating the spread of new technologies [23].

There have been three distinct waves in the history of LF [21]. The first LF was established in Germany at the end of the 1980s, but was widely unknown, as was Penn State University's LF which was established in 1994 [24]. In the first wave, LF were generally established in the USA [14]. In the second wave, LF were implemented across Europe to improve learning experiences in a wide range of applications, sectors, and target groups [24]. During the third wave, the European Learning Factories Initiative (IELF) was founded in 2011 to advance collaboration in the development of learning factories and in 2017, the organization changed its name to "International Association of Learning Factories" (IALF) to make the initiative more accessible to members worldwide [14]. Morphologies have been developing for a variety of purposes such as providing orientation for the design of new LF and defining, distinguishing, comparing, and configuring existing concepts [14]. Tisch et al. created a morphology for learning factories by combining more than 50 features under 7 titles (Operating Model, Purpose and targets, Process, Setting, Product, Didactics, and Metrics) [25]. LF that employ physical products are referred to as LF in the narrow sense, while those that use service products are referred to as LF in the broad sense.

Physical factories are built in specific places and are situated in specific areas. Physical LF allows for greater hands-on teaching and is a perfect simulation of the actual production environment [26]. In addition, physical LF has limited scalability and mobility [25]. In the narrow sense, a LF offers a real value chain for a tangible good so that participants can perform, assess, and reflect on their actions as part of an on-site learning strategy [26]. Digital LF is an IT environment in which all LF elements are digitally monitored, and a virtual LF provides virtual software tools which allow for the execution of the digital simulation, the simulation of tasks, or the evaluation of alternative designs before manufacturing [27]. LFs in a broader sense, including virtual LFs, which comprise almost two-thirds of all LFs [19], have less practical training and are far from reality, though they offer pros like scalability and location independence [26]. While learning factories are primarily focused on education, training, and research, there are many secondary purposes, structures, and target audiences that can be associated with them. Many different themes can be covered by LF from production process improvement, reconfigurability, production and factory layout planning, energy and resource efficiency, factory concept, I4.0, sustainability, product emergence processes, logistics optimization, management and organization, business administration, to automation technology [16]. Additionally, the LF target group is broadly separated into two focus areas, industrial and academic [28]. In these two focus areas, LF appeals to a broad audience, such as students, managers, engineers, or employees [29].

Regional SMEs can benefit from collaboration with LF in practical education, training, and research to adopt I4.0 [30]. Each LF has a different structure since requirements are based on the associated vocational school and training programmes [17]. Likewise, each region may have distinct industry structures, levels of technology, infrastructure, and workforce. A LF should be able to meet the needs of a local industry [8] and it should have attributes appropriate for the region's characteristics and demands to meet these needs.

From the systematic literature review presented in this section it can be concluded the future LF needs to be tailored to follow new megatrends associated with the I5.0 initiative and meet the needs of local industry by providing appropriate skills and competencies for the future workforce.

4. The Learning Factory: Perspectives and Dimensions

4.1 The Learning Factory Perspectives

The primary purpose of the LF is to effectively address challenges regarding the application fields of research, innovation transfer, education and training [24, 31]. Existing LF are closely associated with strategies to support the digitalisation of manufacturing, otherwise known as the I4.0 [31]. However, the I4.0 paradigm is essentially technological and thus it is not fit for purpose in the context of the climate crisis and planetary emergency, nor does it address deep social tensions [6]. As a result of the systematic literature review presented in Section 3, the authors employed a descriptive mental model to map LF portfolios and identify gaps in relation to I5.0, a green and social industrial strategy, across multiple perspectives. The selected perspectives are the main dimensions surrounding I4.0 and I5.0 [3, 39].

- *Technology perspective* grounded in I4.0 initiative and surrounding technologies, such as cloud computing for on-demand manufacturing services, simulation for commissioning, additive manufacturing for flexible manufacturing systems enabled companies to have flexible manufacturing processes and to analyse large amounts of data in real-time, improving strategic and operational decision-making [33].
- *Business perspective* grounded in the circular economy from smart innovation and business value chain design opening the way for business growth [34], supporting vertical and horizontal integration, from field and control levels to production level, operations level, and enterprise planning level on the vertical scale, and from a supplier and the process, information flows, and IT systems in the product development and production stages to logistics, distribution, and ultimately the customer on the horizontal scale [35].
- *Human perspective* has a social dimension that highlights the importance of educating, skilling, reskilling, and upskilling the future workforce and their well-being, the social inclusion and human-technology partnership as support to human capabilities [6], while accounting for user experience from end-users at the front to stakeholders at the back of product-service realization [34].
- *Environment perspective* rooted in sustainability dimension defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [36] with a focus on the promotion of transformation that eliminates the use of fossil fuels, promotes energy efficiency, draws on nature-based solutions, regenerates carbon sinks, restores biodiversity and crafts new ways of thriving in respectful interdependence with natural systems [6].

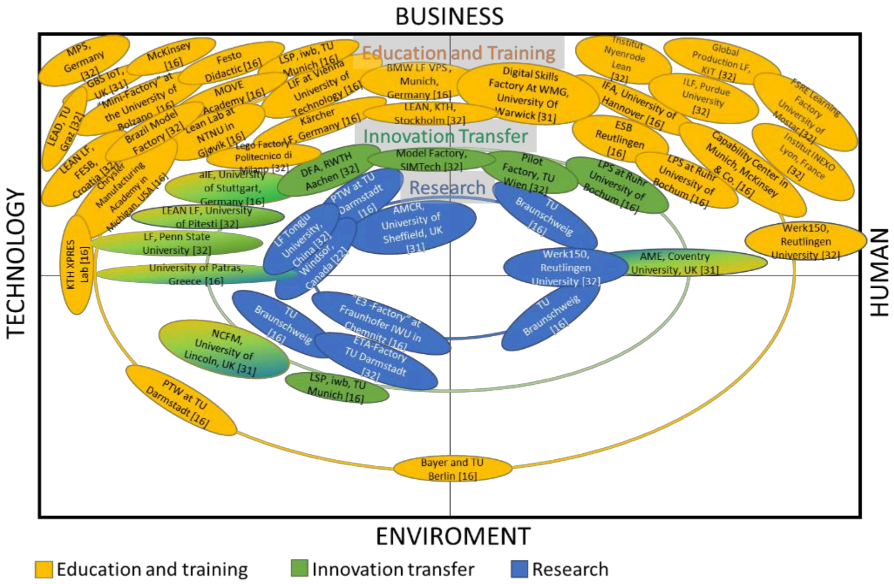

Fig.1. Learning factories mapped through different perspectives.

In Fig. 1 the existing LF are mapped out through technology, business, human, and environmental perspectives with a focus on education and training, innovation transfer, and research presented as orange, green, and blue circles respectively. As depicted in Fig.1, the majority of LF are in upper quadrants with a main focus on education and training in production process improvement, reconfigurability, factory planning, product emergence process, logistics optimisation, etc., and a minority of LF are focused on education, innovation transfer, and research covering aspects of sustainability in particular energy and resource efficiency as presented in the bottom left quadrant. However, from Fig. 1 it can be seen there are no LF in innovation transfer, education and training focusing on human-environmental trends. Consequently, it can be concluded there is a need to develop and pilot the application of skills foresight through learning factories that move past the narrow focus on technology and move on human progress and well-being based on the new forms of sustainable, circular and regenerative economic value creation and equitable prosperity [37]. In Section 4.2 the authors propose an updated morphology adding a new dimension that would help academics and industry to design or reconfigure learning factories covering the skill gap.

4.2 The Learning Factory Dimensions: An Extended Morphology

In recent years, several description models are published used for the characterization and comparison of LF based on the heuristic procedure of morphologic analysis with a focus on particular technical aspects [25]. As with many of their predecessor, the authors used morphologic analysis to draw a holistic and generic picture of learning factories, however, with enough details to classify and draw a correlation between existing options to conceptualize it [26]. The developed description model of this paper is an updated morphology based on the definition and the dimensions of learning factories identified in [26]. The updated morphology presented in Fig. 2 has 8 dimensions, 63 characteristcs, and associated attributes where the new dimension is sustainability that covers human-environmental trends, namely, resilience [38], environmental sustainability [39], workforce sustainability [40], and learning sustainability [41].

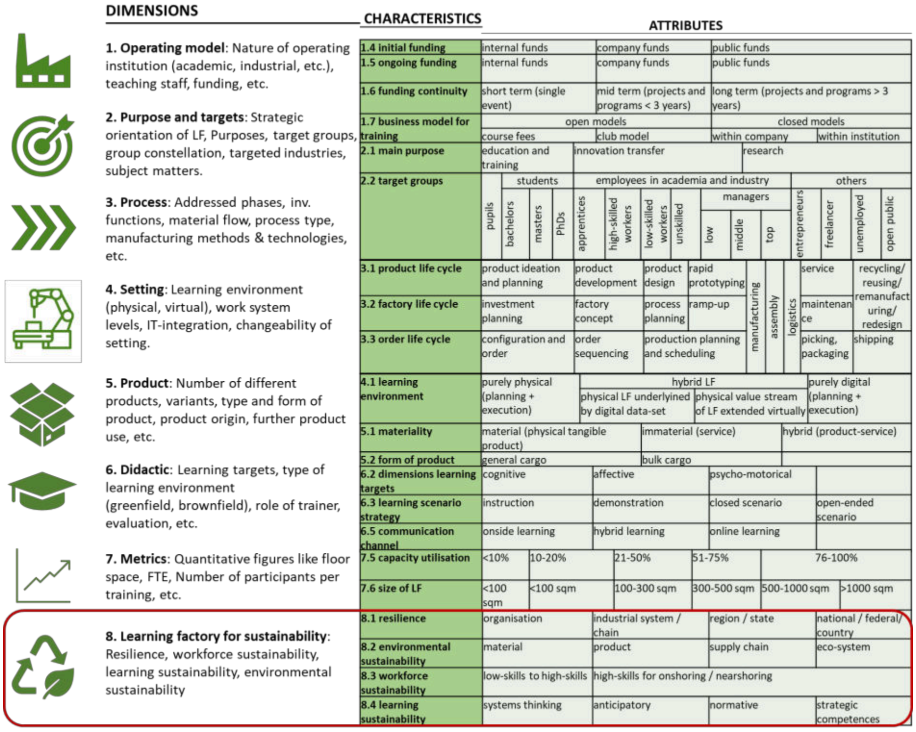

Fig. 2. Extended learning factory morphology with extract shown in Ref [26].

The aspect of sustainability inevitably affects many of the pre-existing dimensions, for example, the manufacturing methods and technologies used are directly correlated with sustainability efforts and environmental impact, and the products' origins and their further product use [45]. However, the approach taken here is to look at sustainability through the lens of the I5.0 dimensions. As such, the method followed to develop the morphology was done by reviewing of the I5.0 dimensions in different contexts to identify how they can be adapted to a learning factory environment. The presented morphology as a reflection on I5.0 is not the final act, and it is expected to develop further including verification and validation of the proposed update. The implications of this proposed update are the key considerations.

5. Limitations and Opportunities

Learning factories come with their drawbacks of limited resources, limited mapping capabilities, limited scalability, limited mobility, and limited effectiveness to name a few [24]. Furthermore, there are many future suggestions about LF proposed by other authors, however, in this paper, the authors name challenges and opportunities worth further investigating to conceptualize the future learning factories in the context of I5.0.

Learning system for problem solving/exploring. Learning processes in manufacturing education and training are both supported and improved through experiential learning in the LF [24]. Furthermore, as far as the LF potential for education and research it is fair to say that existing LF as a learning system facilitates problem-solving [42]. New emergent technologies enable us to focus equally on exploring problems, identifying new ones, and providing solutions in early-stage product and process development. [43]. The question worth further investigating is **"*Could future learning factories support both problem-exploring and problem-solving?"***

Learning factory as a facilitator of competencies for the future workforce. Digitization is changing our world and shaping the challenges of the future workforce. Managing such disruptions is anchored in the principles of sustainability and values to mitigate inequalities by managing tensions between the planet, people, and profit [45, 46]. Although, existing research indicates that smart factories can foster technical competencies module or project-related, and non-technical competencies such as information literacy, problem-solving there is a need for the future workforce to develop both digital multidisciplinary competencies [17] and non-technical, career sustaining competencies [44]. Essential digital multidisciplinary competencies are the attitude towards digitization, the correct usage of copyright, the application of security, the appropriate virtual collaboration, etc. [17], where the main non-technical sustaining competencies are learning through reflection, creation, and articulation of knowledge; speculate and identify gaps that foster innovation; to ask questions, actively listen, reflect, and identify gaps and opportunities worthy of further investigation; to make decisions using incomplete information; to think critically and identify a way forward [44]. The question worth further investigating is **"*What is demanded competencies for Industry 5.0 that can be facilities through learning factories?"***

Learning factory for supporting regional SMEs and reducing regional disparities. Industrial and technological progress has strong agglomeration effects and industry tends to concentrate on the more innovative, leading regions bringing the risk of skill deficits, and technological unemployment [38]. Furthermore, the enabling technologies surrounding I4.0 are easily widespread in developed production regions that have strong technological capabilities and technological infrastructure than in lagging regions [46], which may further exacerbate socio-economic and geographical disparities [47]. At risk are regions with SMEs that have difficulty being highly skilled in applications and technologies of I 4.0 [48]. Nevertheless, the regions with traditionally rather small SMEs need the support and knowledge to develop those skills in an effective way that can be accomplished [48]. The question worth further investigating is **"*Could learning factories support the needs of regional SMEs and unlock latent comparative advantages of a region?*"**

6. Conclusion

Industry 4.0 has significantly progressed the manufacturing industry in the last decade. Digitalization has been prioritized by many manufacturing organizations, but has overlooked important environmental and social needs. Therefore, Industry 5.0 has been proposed to address human-centricity, sustainability, and resilience Learning factories as a key tool to improving the manufacturing sector needs to accommodate these missing aspects in their design or reconfiguration activities. An improved morphology for LF has been proposed to include key aspects such as resilience, environmental sustainability, workforce sustainability, and learning sustainability. Finally, the authors propose thematic areas that need to be investigated to further exploit the utility and the impact that LF can have on the future workforce in the manufacturing sector, the industrial regional development that LF can have via SMEs, and how LF can support problem-solving and exploring in education and research.

References

[1] Attiah, E., The role of manufacturing and service sectors in economic growth: an empirical study of developing countries. 2019.

[2] Rajab, S., M. Afy-Shararah, and K. Salonitis, Using Industry 4.0 Capabilities for Identifying and Eliminating Lean Wastes. Procedia CIRP, 2022. 107: p. 21-27.

[3] Khin, S. and D.M.H. Kee, Factors influencing Industry 4.0 adoption. Journal of Manufacturing Technology Management, 2022.

[4] Afy-Shararah, M. and N. Rich, Operations flow effectiveness: a systems approach to measuring flow performance. International Journal of Operations & Production Management, 2018.

[5] Huang, S., et al., Industry 5.0 and Society 5.0—Comparison, complementation and co-evolution. Journal of Manufacturing Systems, 2022. 64: p. 424-428.

[6] Renda, A., et al., Industry 5.0, a transformative vision for Europe: governing systemic transformations towards a sustainable industry. European Commission, Directorate-General for Research and Innovation https://doi. org/10.2777/17322, 2022.
[7] Xu, X., et al., Industry 4.0 and Industry 5.0—Inception, conception and perception. Journal of Manufacturing Systems, 2021. 61: p. 530-535.
[8] Quinn, W., et al., A Learning Factory Framework: Challenges and Solutions for an Irish University. IFAC-PapersOnLine, 2022. 55(10): p. 631-636.
[9] Ricci, R., D. Battaglia, and P. Neirotti, External knowledge search, opportunity recognition and industry 4.0 adoption in SMEs. International Journal of Production Economics, 2021. 240: p. 108234.
[10] Karadayi-Usta, S., An interpretive structural analysis for industry 4.0 adoption challenges. IEEE Transactions on Engineering Management, 2019. 67(3): p. 973-978.
[11] Raj, A., et al., Barriers to the adoption of industry 4.0 technologies in the manufacturing sector: An inter-country comparative perspective. International Journal of Production Economics, 2020. 224: p. 107546.
[12] Milisavljevic-Syed, J., J.L. Thames, and D. Schaefer, The digitization of design and manufacturing: A state-of-the-art report on the transition from strategic vision to implementation in industry. Procedia CIRP, 2020. 93: p. 575-580.
[13] Horváth, D. and R.Z. Szabó, Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities? Technological forecasting and social change, 2019. 146: p. 119-132.
[14] Abele, E., J. Metternich, and M. Tisch, Learning factories. Concepts, Guidelines, Best-Practice Examples, 2019.
[15] Demirkesen, S. and A. Tezel, Investigating major challenges for industry 4.0 adoption among construction companies. Engineering, Construction and Architectural Management, 2021. 29(3): p. 1470-1503.
[16] Abele, E., et al., Learning factories for future oriented research and education in manufacturing. CIRP annals, 2017. 66(2): p. 803-826.
[17] Roll, M. and D. Ifenthaler, Learning Factories 4.0 in technical vocational schools: can they foster competence development? Empirical Research in Vocational Education and Training, 2021. 13(1): p. 1-23.
[18] Marmier, F., et al. Industry 4.0 Learning Factory: a canvas for specifications. in Proceedings of the Conference on Learning Factories (CLF). 2021.
[19] Pittich, D., R. Tenberg, and K. Lensing, Learning factories for complex competence acquisition. European Journal of Engineering Education, 2020. 45(2): p. 196-213.
[20] Adolph, S., M. Tisch, and J. Metternich, Challenges and approaches to competency development for future production. Journal of International Scientific Publications–Educational Alternatives, 2014. 12(1): p. 1001-1010.
[21] Assad, F., et al. A Literature Survey of Energy Sustainability in Learning Factories. in 2020 IEEE 18th International Conference on Industrial Informatics (INDIN). 2020. IEEE.
[22] Baena, F., et al., Learning factory: The path to industry 4.0. Procedia manufacturing, 2017. 9: p. 73-80.
[23] Schallock, B., et al., Learning Factory for Industry 4.0 to provide future skills beyond technical training. Procedia manufacturing, 2018. 23: p. 27-32.
[24] Tisch, M. and J. Metternich, Potentials and limits of learning factories in research, innovation transfer, education, and training. Procedia Manufacturing, 2017. 9: p. 89-96.
[25] Tisch, M., et al., Learning factory morphology–study of form and structure of an innovative learning approach in the manufacturing domain. Turkish online journal of educational technology, 2015. 14(Special Issue 2): p. 356-363.
[26] Abele, E., et al., Learning factories for research, education, and training. Procedia CiRp, 2015. 32: p. 1-6.
[27] Andrés, M., G. Álvaro, and M. Julián. Advantages of learning factories for production planning based on shop floor simulation: A step towards smart factories in industry 4.0. in 2019 IEEE World Conference on Engineering Education (EDUNINE). 2019. IEEE.
[28] Tisch, M., et al., Learning factory design: a competency-oriented approach integrating three design levels. International journal of computer integrated manufacturing, 2016. 29(12): p. 1355-1375.
[29] Grube, D., A.A. Malik, and A. Bilberg, SMEs can touch Industry 4.0 in the smart learning factory. Procedia Manufacturing, 2019. 31: p. 219-224.
[30] Centea, D., et al., Using the SEPT learning factory for the implementation of industry 4.0: case of SMEs. Procedia Manufacturing, 2020. 45: p. 102-107.
[31] Edwards, S., The opportunity for learning factories in the UK: a report to the Gatsby Foundation. 2021.
[32] Factory, S. Directory of Learning Factories. Available from: https://www.learningfactories.eu/.
[33] Dalenogare, L.S., et al., The expected contribution of Industry 4.0 technologies for industrial performance. International Journal of production economics, 2018. 204: p. 383-394.
[34] Jiao, R., et al., Design engineering in the age of industry 4.0. Journal of Mechanical Design, 2021. 143(7).
[35] Milisavljevic-Syed, J., et al., Architecting Networked Engineered Systems. 2020: Springer.
[36] Geissdoerfer, M., et al., The Circular Economy–A new sustainability paradigm? Journal of cleaner production, 2017. 143: p. 757-768.
[37] Collier, I. and P. Shakespeare, Manufacturing the Future Workforce. High Value Manufacturing Catapult/Gatsby Foundation https://hvm. catapult. org. uk/mtfw, 2020.
[38] Leng, J., et al., Industry 5.0: Prospect and retrospect. Journal of Manufacturing Systems, 2022. 65: p. 279-295.
[39] Bi, Z., Revisiting system paradigms from the viewpoint of manufacturing sustainability. Sustainability, 2011. 3(9): p. 1323-1340.
[40] Hayter, S., The social dimension of global production systems: A review of the issues. ILO working paper, 2004(25).
[41] Hvidsten, T., et al., Sustainability issues across educational disciplines in learning factories. Available at SSRN, 2022.
[42] Maudsley, G., Do we all mean the same thing by "problem-based learning"? A review of the concepts and a formulation of the ground rules. Academic medicine, 1999. 74(2): p. 178-85.
[43] Obieke, C., J. Milisavljevic-Syed, and J. Han, Supporting Design Problem-exploring with Emergent Technologies. Procedia CIRP, 2020. 91: p. 373-381.
[44] Mistree, F. and J.K. Allen, Non-technical Competencies for Succeeding as a Designer in a Digitally Transforming Workplace, in Design for Tomorrow—Volume 2. 2021, Springer. p. 243-250.
[45] Haddad, Y., et al., The transition to environmentally sustainable production: a roadmap timeline methodology. Procedia CIRP, 2021. 103: p. 79-84.
[46] Corradini, C., E. Santini, and C. Vecciolini, The geography of Industry 4.0 technologies across European regions. Regional Studies, 2021. 55(10-11): p. 1667-1680.

[47] Barzotto, M., et al., Smart specialisation, Industry 4.0 and lagging regions: some directions for policy. Regional Studies, Regional Science, 2020. 7(1): p. 318-332.
[48] Faller, C. and D. Feldmüller, Industry 4.0 learning factory for regional SMEs. Procedia Cirp, 2015. 32: p. 88-91.

The learning factory through the sustainability lens

Milisavljevic-Syed, Jelena

2023-06-07