Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 32 (2015) 76 – 81

www.elsevier.com/locate/procedia

The 5th Conference on Learning Factories 2015

Competence development for the holistic design of collaborative work systems in the Logistics Learning Factory

Vera Hummel[a], Kathrin Hyra[a], Fabian Ranz[a], Jan Schuhmacher[a,*]

a ESB Business School, Reutlingen University, Alteburgstraße 150, 72762 Reutlingen, Germany

* Jan Schuhmacher, M.Sc.. Tel.: +49-7121-271-3112. *E-mail address:* jan.schuhmacher@reutlingen-university.de

Abstract

Shorter product life cycles and emerging technologies in the field of industrial equipment are changing the prerequisites and circumstances under which the design of assembly and logistics systems takes place. Planners have to adapt the production in accordance with the underlying product at a higher pace, oversee a more complex system and – most importantly – find the ideal solution for functional as well as social interaction between humans and machines in a cyber-physical system. Such collaborative work systems consider the individual capabilities and potentials of humans and machines to combine them in a manner that assists the operator during his daily work routine towards more productive, less burdening work. To be able to design work systems which act on that maxim, specific competences such as the ability of integrated process and product planning as well as systems and interface competence are required. The ESB Logistics Learning Factory trains students as well as professionals to gain such qualification by providing a close-to-reality learning environment based on a didactical concept which covers all relevant methods for ergonomic work system design and a state-of-the-art infrastructure composed of an manual assembly system, service robots, visual assistance systems, sensor-based work load monitoring and logistical resources. Group-based, activity oriented scenarios enable the participants to put the learnings into practice within their professional environments. By this, Learning Factories have an indirect impact on the transfer of proven best practices to the industry and thereby on the diffusion of the idea of a human-centric working environment.

Peer-review under responsibility of the organizing committee of 5th Conference on Learning Factories (CLF 2015)

Keywords: Learning Factory; Logistics; Human-Machine-Interface; Collaboration; Interaction; Ergonomics; Cyber-Physical Systems; CPS

1. Introduction

Manufacturing companies are currently facing socio-technological trends which are expected to influence the general conditions under which value creation takes place [1, 2]. The emergence of new technologies and increasingly shorter product life cycles as technology related trends combined with the social megatrend of an ongoing demographic change in various leading industrial nations will lead to fundamental changes. These upcoming changes are affecting the technical infrastructure of manufacturing facilities as well as the interaction between employees and machines within new, so-called cyber-physical production systems (CPPS). CPPS will result in a global crosslinking of machineries, storage and logistics systems and other means of production. This especially includes a horizontal, real-time optimized integration of value adding networks, the digital consistency of all engineering processes along the complete product lifecycle as well as the corresponding value stream, combined with the vertical integration and up-linking of the involved production systems. Within CPPS, employees, machines and resources will communicate and collaborate like in a social network. In line with the technological changes, the role of employees as well as the requirements and competence profiles of those operating within such systems are going to change vastly [3, 4].

Peer-review under responsibility of the organizing committee of 5th Conference on Learning Factories (CLF 2015)
doi:10.1016/j.procir.2015.02.111

As a consequence of the demographic change in Europe and many other developed countries, the age structure of employees is going to change by means that the share of young employees is going to decrease and consequently leads to an ageing of the workforce [5, 6]. In line with the growing ratio of older people, work systems have to be adapted to cope with new requirements. As a response to this development and to ensure employability during all phases of the occupational life cycle, innovative technical assistance systems [1] already available today can be deployed to assist the employees and reduce burdening phenomena such as stress and strain. To cope with these changes specific strategies are needed for the competence development of those who are in charge of designing such human-centered, technology-based work systems. Besides activities to sensitize the workforce regarding new available technologies and a fundamental understanding of the core methods of human-centered workplace design, relevant competences needed for an human-centric interaction between employees and machineries - respectively CPS - must be addressed [4, 7]. The outstanding significance of qualified personnel as a key factor for a successful implementation of innovative technologies like CPS and the configuration of state-of-the-art human-machine-interfaces within the factory is proven by several surveys and studies [8, 9]. In this regard, learning factories like the *Logistics Learning Factory* of the ESB Business School, a faculty of Reutlingen University, serve as close-to-reality learning environments, which can be used to inform, sensitize and educate different target groups.

2. The role of humans

Scientists, employer representatives and labor unions consent on the future role model of employees who are designing and/or operating manufacturing systems that are subject to the described socio-technological impacts [10-12]. This will not only affect the machine-to-machine communication, but also the interaction between employees and physical objects in *collaborative* work environments. Consequently, the technological progress will lead to a change of tasks of employees and a shift of the required competences and job specifications [13] which especially will involve the natural capacities of the employees like intelligence, creativity and empathy [14].

A feasible role of employees in a future cyber-physical work environment will be a function in supervision of the superior production strategy, combined with the role of a creative and skilled problem solver who is dealing with occurring issues within the work system ad-hoc. To intervene in the cyber-physical production system (CPPS), the employee will be assisted by various flexible, partly mobile human-machine-interaction solutions and gain a higher level of responsibility [13]. In doing so, the employee will use aggregated real-time information from the CPPS to derive actions or interventions after interpreting the available data. Beyond information purely related to operations, also ergonomic data can be ascertained and considered by those steering and optimizing the socio-technological work systems. At the *ESB Logistics Learning Factory,* learners can slip into that described role: a so-called “stress and strain cockpit” is used to assess stress and strain of employees and to feed the generated ergonomic data back to the digital planning environment, allowing real-time system adaption.

3. Competencies and qualification

Even in the highly technological field of CPPS there will be simple tasks for less qualified employees [12]. The reason is not caused by technological limitations, but rather economic reasons, which militate against automating these processes. For these tasks, innovative technical assistance systems, like collaborative robots, have a high potential to create less burdening work systems to cope with the intensifying demographic change. Nevertheless, the growing penetration of CPPS will cause a higher demand for highly qualified engineers with profound IT and collaborative work system design skills [15].

To parallelize the employee qualification and training processes with the technological and social changes taking place in the industry, specific qualification strategies and concepts have to be developed or existing concepts must be adapted respectively. Amongst others, a basic understanding of how to use the available data sources in an efficient way and specific professional and methodical competences are essential to implement a CPPS [13]. The required qualification measures, covering elements of various engineering disciplines to train the needed competences and system awareness of these production systems, have to be addressed to all employees reaching from skilled workers to engineers [15].

4. Learning Factories

Changing skill requirements lead to a changing use of teaching and learning methods, which can also meet specific training objectives in the fields of planning, implementation and optimization of work and logistics systems. Overall, a growing interest in practical and experiential teaching or learning environments can be determined. As a result, leading universities and colleges react by establishing learning factories [16-19]. These physical, operational factories usually cover the whole creation process of a product selected in accordance with didactical criteria and serve as exemplary and realistic learning environments. The concept of learning factories integrates self-directed and action-oriented learning in heterogeneous groups to encourage implied experiential knowledge, integrated into a formal didactical concept. This enables the trainer to address the intended competences systematically by guiding the learners through the processes necessary to acquire the intended knowledge and professional and/or vocational competencies. This symbiotic combination of teaching professional expertise, methodical and individual competencies as well as soft skills [20, 21] can be achieved by combing traditional, instructor-based teaching methods with hands-on sessions held in teamwork to improve social and group work competencies. The tasks or problems students get confronted with are inspired by issues of high practical relevance and designed openly to avoid predefined solutions or approaches. By using mostly commercially available technologies in learning factories, a very authentic learning environment can be created, resulting in a highly immersive experience for the learners [22]. Additionally, higher learning success is achieved by including the own actions of and the interactions between the learners into the learning experience compared to conventional teaching and learning methods [19, 23].

5. ESB Logistics Learning Factory

The major aim of the ESB Logistics Learning Factory (LLF) at Reutlingen University is the development of a training instrument to gain professional action competence in the field of the design and optimization of flexible and versatile work and logistics systems including the ergonomic evaluation of these systems. The production system is focused on the assembly of multi-variant series products, including the use of innovative technologies like CPS. The overall concept regarding the knowledge and competence development of the LLF is composed by defined learning goals and the corresponding learning contents and methods of work and logistics system design, strategies to achieve action competence as well as the learning environment which covers digital tools for an integrated product and process planning and the physical infrastructure to realize the developed solutions.

5.1. Curriculum

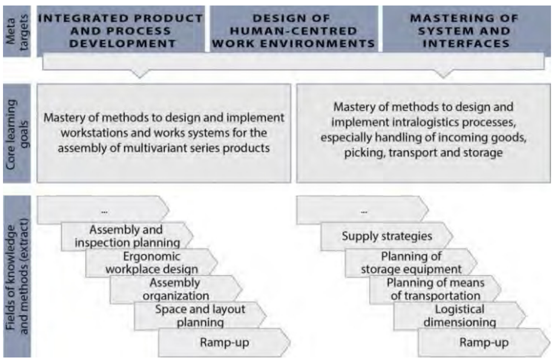

Fig. 1: Learning goals and curriculum

The curriculum of a learning factory consists of defined learning goals which are referring to the competences participants should develop. These competences are divided into partial competences, for which the required explicit and implicit knowledge must be determined, processed and integrated into the curriculum [24]. For the LLF, core learning goals are defined in the field of work and logistics systems design. Also, meta-targets which should enable participants to cope with different surrounding conditions, requirements and different technical and organizational possibilities in future production environments have been defined (see Fig. 1).

5.2. Product

The product of the LLF is a city scooter, which allows the assembly of four different basic variants. By using generative manufacturing methods, the students can increase the number of variations and integrate them into the previous production processes. The city scooter is composed of roughly 50 parts, which allows a sufficient complexity for workflow planning tasks. Moreover, instead of complex and irresolvable joints, the city scooter requires assembly procedures (according to DIN 8593-1) only, which allow the reuse of the scooter in the learning factory. All in all, this product gives various opportunities for individualization, modularization, the use of preassemblies etc. so that different qualification scenarios with specific foci can be designed by using this product.

5.3. Infrastructure

The LLF is equipped with a continuously integrated product and process planning environment (Engineering & Operations Cockpit (EOC)) as well as various kinds of physical infrastructure, allowing the design of realistic work and logistics systems. Based on the defined product and fictional customer orders this learning environment allows students to plan, validate, realize and optimize a production system holistically.

5.3.1. Digital planning environment

The EOC fulfils the requirement for an integrated digital engineering covering the entire value chain as described by [25]. Important components of the EOC are tools for product, process and ergonomic workplace design and tools for factory layout planning, material flow simulation and production planning and monitoring. All phases of the value creation process from the product design to distribution are virtually captured within this system. By using *CATIA* for product planning and *DELMIA* for process and resource planning, most of the overall required data and functionalities are integrated in the same platform. To enrich the design data of the product with the required assembly times the software tool *MTM TiCon* is in use. Based on this information, the tact time of the assembly system can be determined and work schedules and instructions can be created within the material execution system *becosMES* user interface or separately on any end user device through HTML5. Accordingly, changes regarding products and processes can be examined digitally to identify required adaptions of the physical work system. Through an online shop, customer orders are generated, processed by the manufacturing execution system and finally allocated to the corresponding work places in the physical learning factory. The information flow is designed bi-directionally to allow both the distribution of information to different locations within the factory as well as in opposed direction back to the planning environment based on information generated at the shop floor level enriched by the data produced by the stress and strain cockpit (see chapter 5.4) to include the employees' individual physical condition into planning. The gained information can be aggregated, analyzed and interpreted by the learners to optimize und restructure the production system within the EOC to validate improvements digitally before the changes are executed in the physical environment. Also, instructors can use this digital environment to initiate rescheduling actions or introduce turbulences (e.g. additional high priority customer orders, malfunction of infrastructure etc.) which have to be solved by the participants.

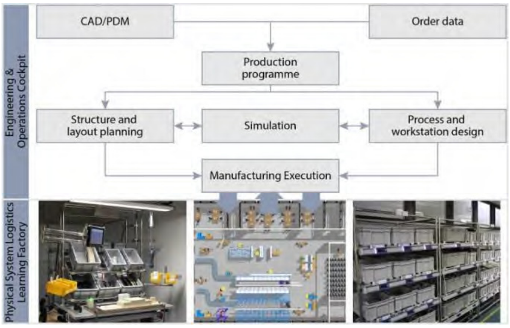

Fig. 2: Schematic diagram of the ESB Logistics Learning Factory

5.3.2. Physical learning factory

Following the focus of the LLF, a large variety of assembly and logistics infrastructure as well as equipment for ergonomic evaluation is available for the participants to implement and optimize production systems.

Assembly

A modular pipe construction system from *BeeWaTec* can be used by the learners to build customized assembly, quality check and packaging workstations. It allows the participants to build various kinds of customized physical infrastructure, which also can be reconfigured or optimized easily e.g. following ergonomic issues identified by the use of the stress and strain cockpit. Since all workstations are mobile and are equipped with wireless communication technology and accumulator batteries, there are no limitations regarding changes of the factory layout. The workers at the assembly stations can use mobile tablet-pcs, e.g. to receive orders, to send information back to the planning system or to access multimedia-based work instructions and analysis of specific production processes. The access or feedback of information can be done manually or automatically, e.g. by using RFID-technology embedded on the product itself or on the jigs.

Fig. 3: Assembly workstation at ESB Logistics Learning Factory

Logistics

For storage purposes, racks for boxes and pallets can be built by using the modular pipe system already mentioned. Besides manual pallet trucks and transport trolleys, different kinds of autonomous guided vehicles (AGVs) as well as an intelligent continuous conveyor system can be used for material transport. The AGVs can be implemented as both tractors for tugger trains and shooter racks to automate the material supply of the assembly stations. Routing and navigation of the vehicles is done by using optical tracks or laser-based navigation to allow flexible factory layouts. The modular and entirely locally controlled conveyor system "FlexConveyor" provided by Gebhardt Fördersysteme is a perfect example for a CPS implementation for intralogistics as defined by [26]. By means of the plug-and-play functionality and local control units in each conveyor module, the modules can be combined to user-defined conveying lines without a need of a central control entity.

Human-Machine-Interfaces (HMI)

Besides the previous mentioned tablet-pcs, which are used for bi-directional information exchange between the workstations and the digital planning environment, additional innovative HMI are part of the infrastructure for education, training and research purposes. To automate specific process or to facilitate the work of the workers two collaborative robots (Rethink Robotics Baxter and Universal Robots UR10) can be implemented into the work system. Through sonar and tactile sensors, these robots are able to collaborate with workers without protective fences. These robots also can be taught directly by moving the robot joints, which allows these robots to be integrated quickly for specific tasks directly by the worker. Therefore, learners are able to experience potentials and limitations of collaborative robots, which should not replace the worker but assist him, in a practice oriented manner and examine the effects of this technical assistance system on the capacities, throughput times or physical strain of selected work tasks. For more complex tasks, these robots can be also programmed via the open-source framework ROS. Furthermore, storage racks can be equipped with a pick-by-light system to demonstrate the potential of optical assistance systems, e.g. the impact on efficiency and quality of picking or versatile assembly processes. In addition, the self-developed stress and strain cockpit provides innovative and extensive possibilities for ergonomic evaluation and dynamic planning of processes within the LLF. It can be used in addition to conventional evaluation methods, as the Ergonomic Assessment Worksheet (EAWS), the Key Indicator Method (KIM), or other methods usually used in practice. The cockpit uses different types of sensors to measure individual-related data, which are automatically analyzed and processed by a logical system structure which is an essential element of the stress and strain cockpit. Through a constant feedback, realized by interconnectivity between the cockpit and the higher-level systems, a real-time evaluation is facilitated, what makes potential for corrective interventions visible.

5.4. Interconnectivity on the example of the work system stress and strain cockpit

Fully cross-linked manufacturing environments offer potentials for completely new information flow and control systems which enable dynamic planning of all business processes in real-time based on various kinds of information [3, 8]. In the ESB Logistics Learning Factory, various projects for linking the persisting physical infrastructure with the digital planning environment were launched. Systems that are used mostly parallel so far now have to be connected and consequently will enable a continuous, interactive and dynamic planning process in real-time through reconciliation of the desired and the actual conditions. Besides the bidirectional information flow of specific production data with a direct feedback to the digital planning system through determined KPI describing the actual status of the work system, the following example describes the specifically developed stress and strain cockpit, which includes real-time individual ergonomic data into planning. The stress and strain cockpit (see Fig. 4) constitutes a comprehensive approach for a systematic and consistent evaluation of the stress status and the individual strain of employees in the manufacturing industry. However, this system is not only a good example for connectivity between different systems, but also shows an approach to address the changing age structure of production personnel due to the ongoing demographic change [1].

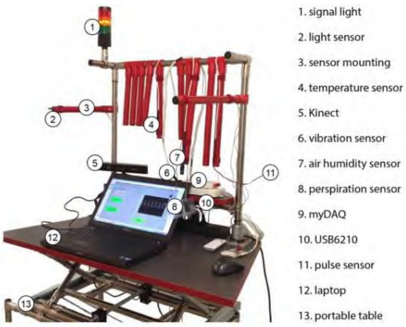

Fig. 4: Stress and Strain Cockpit

The system provides information in real-time about the stress and strain status of workers and can be used in addition to established evaluation methods of ergonomics. The cockpit is composed of different types of sensors which generate data regarding the individual condition of a worker automatically and in real-time. Through a self-programmed algorithm the measured values are aggregated and interpreted [27]. The relevant data is gathered either on request, as for example age or gender of the person, or is measured by sensors, as the heart rate or perspiration rate. Further environmental influences as temperature, humidity, lighting, or the sound level can be measured and associated to other collected data. All these initially unconnected information can be automatically processed and allow a statement about the actual condition of a worker. An automatic feedback takes place, data is analyzed automatically, linked to other data, and displayed on a dashboard in real-time and used to improve the working system. This real-time ergonomic data gathering and processing method combined with the data generated by the CPS has a huge potential to improve the planning quality of collaborative work systems, since a potential overstress of a worker can be determined within a short period of time. Ultimately, the students can be put into the role of supervising an integrated system of systems and use the delivered information for the continuous optimization of the production system in the learning factory.

To achieve such a crosslinking of different systems, a number of challenges have to be considered. A wide range of interfaces have to be established and operated, gathered data have to be preprocessed to compatible and comparable information, a higher level system for an aggregated view of relevant inform has to be established. Machineries, warehouse and production systems, as well as all other essential objects have to be equipped with sensors or actors and have to be connected to the overall system or even to the internet [27].

5.5. Qualification procedure

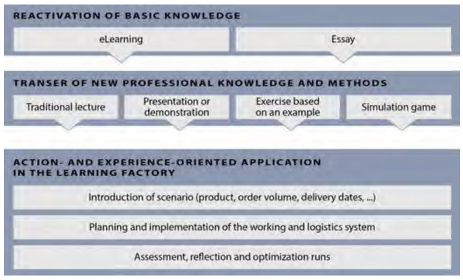

Fig. 5: Qualification procedure

To achieve the given objective of providing the learner with the relevant skills and competences a multi-staged qualification concept is used (see Fig. 5). This concept contains phases of self-study, instruction, practice and the self-dependent action and experience oriented application of methods within a comprehensive and complex task in the learning factory. The self-directed reactivation of basic knowledge is needed to ensure that all participants have the same entry-level of knowledge, what improves time-efficiency of the actual training. To transfer new knowledge and methods, different teaching methods like instructive and constructive learning are combined. This qualification part already takes place in the actual learning factory to make the participants familiar with the used digital and physical infrastructure. The role of the trainer is becoming more and more passive, shifting from a pure instructor to a moderator or coach. Finally, the learners are confronted with the final qualification scenario and receive all required information like product and order data. Based on this information, the learners plan and design their individual operational, collaborative production system. The trainers are only assisting the learners in case of questions regarding the used technical assistance systems at this stage of the qualification procedure. During the actual operation of the factory the trainer may introduce some turbulence, which is forcing the learners to change their planning and to reconfigure the collaborative, socio-technical working system. An objective evaluation of the execution of the given task can be conducted based on specific indicators like the capacity utilization, throughput times, quality performance indicators, on-time delivery or ergonomic measures from the stress and strain cockpit. But more important than these objective criteria is the reflection of the learners group regarding the learned methods, the made decisions and the exchange of individual experiences according to the adopted role within the team.

6. Summary and outlook

Learning factories have proven to be an appropriate medium to develop the required system and interface understanding, to enable the participants to implement product- or production-based innovations as well as to train future industrial engineers to design or reconfigure the subsequent processes under strong consideration of human factors. The ESB Logistics Learning Factory uses commercially available technologies, enhanced by in-house developed solutions, to create a try-and-error learning environment covering the central aspects of integrated working and logistics systems. Different examples for human-machine-collaborations can be demonstrated and used for qualification measures. Not only methods and tools covering different aspects of industrial engineering are taught in a practice-oriented manner, but also the development of practical knowledge and the introduction of innovative, easy to handle production technology (like 3D-printing) into a so-called "System of Systems" are part of the learning factory concept. Also, the ESB Logistics Learning Factory is a test-bed for researchers to develop innovative systems like the stress and strain cockpit, which allows the researchers to test and improve their systems in practice and to give learners an insight into current fields and activities of research. In addition, emerging technologies are evaluated regularly regarding their potential practical use and (in case of a positive result) will be integrated into the curriculum. A central aim of the ESB Logistics Learning Factory in this area is to identify solutions for future-oriented, human-centered work systems, which are also attractive for small and medium sized enterprises and to qualify their employees for the design of innovative work environment solutions. Right from the startup in 2014 it receives appreciation from the student body, objectified e.g. through higher attendance rates and improved evaluations of those lectures on both B.Sc. and M.Sc. level that are now held in the ESB Logistics Learning Factory and also gained interest from the industry side, so that first training programs could be developed and performed with external participants – again, receiving very positive feedback. Based on these experiences and first successes, the learning factory will be further integrated into the different degree programs' curricula and VET offers will be expanded.

References

[1] Abele, E., Reinhart, G. (2011): Zukunft der Produktion: Herausforderungen, Forschungsfelder, Chancen. Carl Hanser Verlag, Munich, p. 10-24.

[2] Gausemeier, J., Wiendahl, H.-P. (ed.) (2010): acatech diskutiert: Wertschöpfung und Beschäftigung in Deutschland. acatech – Deutsche Akademie der Technikwissenschaften, Munich, p. 27-32.

[3] Kagermann, H., Wahlster, W., Helbig, J. (2013): Umsetzungsempfehlungen für das Zukunftsprojekt Industrie 4.0: Abschlussbericht des Arbeitskreises Industrie 4.0.

[4] Kagermann, H. (2013): Impuls − Zukunftsbild Industrie 4.0. Transfer-Konferenz AUTONOMIK des BMWi. Berlin, January 31st 2013.

[5] Statistische Ämter des Bundes und der Länder (2011): Demografischer Wandel in Deutschland: Bevölkerungs- und Haushaltsentwicklung im Bund und in den Ländern, Statistisches Bundesamt, Wiesbaden, p. 8.

[6] Linz, K., Stula, S. (2010): Demographic change in Europe - An Overview: Working paper no. 4 of the Observatory for Sociopolitical Developments in Europe, Institute for Social Work and Social Education (ISS), Frankfurt a. M. – Germany, p. 2-4.

[7] Schlund, S. (2013): Zukunftsprojekt Industrie 4.0 – Ziele und Kontext. Grenzenlose Arbeitswelten 2025. Stuttgart, September 17th 2013.

[8] Spath, D. (Ed.) (2013): Produktionsarbeit der Zukunft – Industrie 4.0. Fraunhofer Verlag, Stuttgart, p. 50-56.

[9] Glatz, R., Diegner, B., Dorst, W. (2013): Tendenzumfrage der Plattform Industrie 4.0 - Ergebnisse Januar – Februar 2013. Plattform Industrie 4.0.

[10] Gerst, D. (2014): Arbeitspolitische Konsequenzen aus Industrie 4.0. Presentation at 5th Industrial Engineering Fachtagung 2014 in Dortmund.

[11] Gerst, D., Schweppe, K. (2014): Wie verändert Industrie 4.0 unsere Arbeitswelt?. Presentation at 5th Industrial Engineering Fachtagung 2014 in Dortmund.

[12] Steiger, H., Hartbrich, I. (2014). Industrie 4.0: Wir brauchen eine neue Arbeitskultur. VDI Nachtrichten, No. 29 (2014).

[13] Gorecky, D., Schmitt, M., Loskyll, M. (2014): Mensch-Maschine-Interaktion im Industrie 4.0-Zeitalter. In: Bauernhansl, T., ten Hompel, M., Vogel-Heuser, B. (Ed.). Industrie 4.0 in Produktion, Automatisierung und Logistik: Anwendung, Technologien, Migration. Springer Vieweg, Wiesbaden, p. 525-527.

[14] Schließmann, A.. (2014): iProduction, die Mensch-Maschine-Kommunikation in der Smart Factory. In: Bauernhansl, T., ten Hompel, M., Vogel-Heuser, B. (Ed.). Industrie 4.0 in Produktion, Automatisierung und Logistik: Anwendung, Technologien, Migration. Springer Vieweg, Wiesbaden, p. 451.

[15] Lüder, A. (2014): Integration des Menschen in Szenarien der Industrie 4.0. In: Bauernhansl, T., ten Hompel, M., Vogel-Heuser, B. (Ed.). Industrie 4.0 in Produktion, Automatisierung und Logistik: Anwendung, Technologien, Migration. Springer Vieweg, Wiesbaden, p. 503.

[16] Abele, E., Cachay, J. (2012): Kompetenzentwicklung durch Lernfabriken: Lehrplan für Shopfloor-Mitarbeiter bei proaktiven Verbesserungsprozessen. wt Werkstattstechnik online, Volume 102 (2012), Issue 3, p. 88-93.

[17] Bauernhansl, T., Dinkelmann, M., Siegert, J. (2012): Lernfabrik advanced Industrial Engineering – Teil 1: Lernkonzepte und Struktur. wt Werkstattstechnik online, Volume 102 (2012), Issue 3, p. 80-83.

[18] Plorin, D., Poller, R., Müller, E. (2013): advanced Learning Factory (aLF) – Integratives Lernfabrikkonzept zur praxisnahen Kompetenzentwicklung am Beispiel der Energieeffizienz. wt Werkstattstechnik online, Volume 103 (2013), Issue 3, p. 226-232.

[19] Tietze, F., Czumanski, T., Braasch, M., Lödding, H. (2013): Problembasiertes Lernen in Lernfabriken – Ingenieursausbildung und Weiterbildung im Bereich der schlanken Produktion. wt Werkstattstechnik online, Volume 103 (2013), Issue 3, p. 246-251.

[20] Gerst, D. (2007): Humanressourcen. In: Arnold, D.; Isermann, H. et al. (Ed.): Handbuch Logistik. Springer-Verlag, Berlin.

[21] Ott, B. (2011): Grundlagen des beruflichen Lernens und Lehrens – Ganzheitliches Lernen in der beruflichen Bildung. 4. Auflage. Cornelsen, Berlin.

[22] Steffen, M., Frye, S., Deuse, J. (2013): Vielfalt Lernfabrik – Morphologie zu Betreibern, Zielgruppen und Ausstattungen von Lernfabriken im Industrial Engineering. wt Werkstattstechnik online, Volume 103 (2013), Issue 3, p. 233-239.

[23] Cachay, J., Wennemer, J., Abele, E., Tenberg, R. (2012): Study on action-oriented learning with a Learning Factory approach. Conference paper: 3rd international Conference on New Horizons in Education (INTE), June 5th – 7th 2012, Prague.

[24] Abele, E., Tenberg, R., Wennemer, J., Cachay, J. (2010): Kompetenzentwicklung in Lernfabriken für die Produktion. ZWF, Volume 105 (2010), Issue 10, p. 909-913.

[25] Löwen, U. (2013): Durchgängiges Engineering – ein zentrales Merkmal von Industrie 4.0. Conference on Durchgängige Anlagenplanung 2013, March 20th 2013, Nürnberg.

[26] Becker, M., Timm-Giel, A. (2005): Selbststeuerung in der Transportlogistik: Modellierung der mobilen Kommunikation. In: Industrie Management, Issue 5 (2005), GITO-Verlag, Berlin, p. 71-74.

[27] Hyra, K., Hummel, V. Orso, J. (2014): Belastungs- und Beanspruchungscockpit. In: Tagungsband: „Produktion und Arbeitswelt 4.0 – Aktuelle Konzepte für die Praxis?". Institut für Betriebswissenschaften und Fabriksysteme, Chemnitz, p. 411-420.