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Development of the Industrial IoT Competences in the Areas of Organization, Process, and Interaction based on the Learning Factory Concept

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Abstract

Lately, first implementation approaches of Internet of Things (IoT) technologies penetrate industrial value-adding processes. Within this, the competence requirements for employees are changing. Employees‘ organization, process, and interaction competences are of crucial importance in this new IoT environment, however, in students and vocational training not sufficiently considered yet. On the other hand, conventional learning factories evolve and transform to digital learning factories. Nevertheless, the integration of IoT technology and its usage for training in digital learning factories has been largely neglected thus far. Existing learning factories do not explicitly and properly consider IoT technology, which leads to deficiencies regarding an appropriate development of employees‘ Industrial IoT competences. The goal of this contribution is to point out a didactic concept that enables development and training of these new demanded competences by using an IoT laboratory. For this purpose, a design science approach is applied. The result of this contribution is a didactic concept for the development of Industrial IoT competences in an IoT laboratory.

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Keywords: Digital Learning Factory, Industrial IoT Competences, Student Training, Vocational Training

1. Introduction

The usage of Internet of Things (IoT) technologies in manufacturing is referred to as Industrial Internet of Things (IIoT) [1]. Lately, first implementation approaches of IIoT technologies such as cyber-physical systems and concepts like smart production organization through entity cross-linking, information availability, or decentralized

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decision-making penetrate industrial value-adding processes [2, 3]. Aforementioned is also subsumed under the paradigm of *Industrie 4.0* [4]. This, by technology induced transformation, leads to new roles or even activity types such as, *inter alia*, the system regulator [cf. 5]. A redesign of the manufacturing processes results in new tasks for the employees. Hence, the simultaneous change in processes and, within this, the respective tasks for each role or activity type in an organization is a core characteristic of IIoT technology induced transformations. Aforementioned leads to the transformation of the competence requirements for employees. Those are, amongst others, context sensitive and adequate adaption and steering of changeable processes and lot sizes, machine park organization, and collaborative and interactive working also beyond enterprise borders, as well as the usage of new technologies. Conventional competence facets such as *professional* competence, *personal* competence, *cultural* competence, *methodological* competence, *leadership* competence, and *social* competence are no longer sufficient for employees on the shop floor as well as for white collars to fulfil those requirements [6]. Especially, meta-competences such as employees‘ *organization*, *process*, and *interaction* competences (in the following is referred to them as IIoT competences) are of crucial importance in this new Industrial IoT environment [7, 8]. Unfortunately, however, only the interplay of all these above-mentioned competence facets leads to a context adequate *action* competence.

Learning factories offer a basis for self-controlled and informal learning [9]. Conventional learning factories evolve and transform into digital learning factories. Nevertheless, the integration of IoT technologies and their usage for training in digital learning factories has been largely neglected thus far. Existing learning factories do not explicitly and properly consider IoT technologies. They have to adapt to these new requirements and enhance their education concepts [10]. This leads to deficiencies regarding an appropriate development of employees‘ IIoT competences. Additionally, these IIoT competences are in both, students and vocational training clearly underrepresented [11]. This is due to the evolving novelty of technologies and their application in IIoT (or *Industrie 4.0*) contexts. Hence, a corresponding didactic concept is missing.

The goal of this contribution is to point out a didactic concept that enables development and training of these new demanded competences by using an IoT laboratory as digital learning factory. For this purpose, a design science approach is applied. First, a literature analysis on competences and their facets as well as current learning factory approaches was carried out. On this basis, design and development of both, the didactic concept and the learning environment is presently conducted. First demonstrations are already available. Current activities are: refinement of the competence characteristics, integration of IoT technologies, and development of further learning scenarios within the laboratory. The result of this contribution is a didactic digital learning factory concept for the development of industrial IoT competences.

This contribution is structured as follows. Section 2 briefly describes IIoT and cyber physical systems as main driver of the current developments, resulting requirements for employees, and respective competences. Section 3, firstly, introduces the didactic approach. Additionally, its application in a teaching and learning scenario is then exemplarily illustrated. The conclusions are exemplified in Section 4.

2. IIoT requirements and competences

IIoT incorporates big data technology and machine learning. Data is captured by sensors and processed so that actuators are able to purposefully influence the environment. Further enablers are machine-to-machine communication as well as automation technologies [12]. This leads to a new level of work organization and steering of the value-added chain over the entire product life cycle [13]. The two main driving forces are cyber physical systems and the Internet of Things. Cyber physical systems describe embedded systems, logistic and management processes as well as Internet services [14] which capture physical data via sensors and effect their environment via actuators [15]. Additionally, they analyze as well as store data so that they can actively or reactively interact with the physical or digital world [16]. For this purpose, they are locally and globally connected via digital networks, use worldwide available data and services, and contain multi-modal human machine interfaces for communication within and steering of processes [14]. Thereby, the human factor of integration is mandatory [17]. The Internet of Things, on the other hand, is “a self-configuring, adaptive, complex network that interconnects ’things’ to the Internet through the use of standard communication protocols. The interconnected things have physical or virtual representations in the digital world […] and are uniquely identifiable” [18, p. 74]. The main enabling factor is the integration of technology and communication solutions [cf. 19].

In spite of all technological progress and the resulting changes, human employees remain the decisive critical success factor [17]. Hence, they have to be trained and qualified to fulfil their tasks. Particularly, the employees on the shop floor need to accept these developments and adapt to new roles, technologies, and tasks. Consequently, they have to be prepared for these IIoT induced requirements. This preparation refers to sensitization, training and qualification of the employees. Requirements they are facing are, *inter alia*, due to a high level of interdisciplinarity, the sharing of experiences about products, materials, and work across processes, divisions, and hierarchies or context transferability. They have to organize themselves and other process participants in this new environment. Therefore, an understanding of the process structures is required. Furthermore, employees have to be capable of problem solving, supervision, judgement, holistic thinking, and need to possess an ability of communication and adaptability [20]. The penetration of the processes by technologies could lead to the assumption that robots and machinery will execute simple tasks in the future. A corresponding impoverishment of the task variety of some activity types would be a consequence. However, activity types who execute those kinds of tasks will remain [21]. On the other hand, innovative technical assistance systems can be deployed to assist these employees [22] and other activity types will gain more responsibility with increasing complexity of their tasks.

Competences are a person's capabilities for self-oriented and creative acting in thus far unfamiliar and unknown situations [23]. They are well founded on knowledge, as capability available, consolidated by experience, and realised by will [24]. The above mentioned vocational *action* competence can be decomposed into different competence facets [25]. In addition to *professional*, *personal*, *cultural*, *methodological*, *leadership* and *social* competence also *organization*, *process*, and *interaction* competence facets were identified in [8] as relevant for the IIoT context (Tab. 1).

Table 1. Competence facets.

Facet	Brief description
Professional competence	Comprises the disposability of professional capabilities, skills, and understanding, which are obtained and enhanced in training and applied in action contexts.
Personal competence	Is a persons' disposition and willingness to reflect actions, which means self-estimation and to develop a productive attitude, values and unfold talent, motivation, and performance capability.
Cultural competence	Integrates (a) intercultural as well as (b) professional culture competence. Whereby (a) refers to the handling of people with diverse national cultural background and (b) to the handling of professional specific socialisation processes which lead to specific standards and which constitute an orientation function for group member actions.
Methodological competence	Is a horizontal competence and comprises situation- and interdisciplinary flexible applicable and cognitive capabilities, which also conduce for the acquisition of new knowledge and capabilities.
Leadership competence	Represents the goal-oriented influence of employees as well to put forward a vision, exemplification of values, and the design of the work environment.
Social competence	Is the entirety of the social- communicative abilities of a person or a group, who refer to the creative design of social relationships and processes in a group or organization.
Process competence	Is the disposability of profound knowledge of the entire business process, the process structure, and the manufacturing process as well as the purposeful usage of technical equipment.
Organization competence	Is an employees goal-oriented structuring, planning, organisation of the own resources, machinery and equipment, work pieces and information systems.
Interaction competence	Comprises cooperation and collaboration of employees with other employees and intelligent technical entities and their goal-oriented inter related acting as well as the purposeful operation of technical equipment.

3. Didactic concept of the ACI learning factory

Learning factories are learning environments in which participants are trained by the usage of simulated real production processes, which are as realistically and authentically as possible [26]. They pursue an action-oriented approach for the acquisition of competences by means of structured self-learning processes that are supported by different teaching methods [27]. These teaching methods move the teaching and learning processes close to real industrial situations [10]. Within this, the trainer supports the learner within the processes necessary to acquire the intended knowledge and required competences. Additionally, a framework for the subject inherent existent learning methods is provided.

The IoT laboratory *"Application Center Industrie 4.0"* (ACI) [28, 29], comprises a hybrid simulation environment, which combines the benefits of virtual and hardware simulation and components in order to design or analyse industrial manufacturing processes or value-adding networks. The main physical components are the work pieces and the machine tool demonstrators as well as transport lines which connect various machine tool demonstrators. The demonstrators with their ability to communicate in different ways and the flexible transport system provide an effortless integration of hardware components into the overall system. The software is designed for a quick integration of sensors, actuators, and other devices using standard communication protocols such as OPC UA. The hardware components provide the interfaces for an easy connection and integration of new hardware. The laboratory's investigation focuses are against the present background in particular:

- Integration of IIoT technologies into industrial processes,
- Demonstration of advantages and disadvantages of their application, and
- Analysis of their usability.

For the purpose of developing IIoT competences, a distinctive didactic concept is currently being developed and implemented within the ACI learning factory. Thus, the laboratory can be used as digital learning factory for the training of students and practitioners.

3.1. Teaching and learning concept

Learning is fundamental for obtaining competences. To overcome an outdated definition of "learning", the concept distinguishes between "teaching" and "learning". "Teaching" is understood as external assistance to support the participants in gaining and developing competences. "Learning" on the contrary, is considered as a subject's inner process, which cannot directly be determined by external influences. Whereby especially in IIoT context - in which the changes are usually imposed *top down* - resistance to learn is often a resulting effect [30]. In response, the didactic concept (Fig. 1) pursues a participative three-phase approach, in which the enterprises predefine the framework, the employees, however, are positioned as equal partners. This leads to the role of the trainer as learning companions so that the employees' individual action problems can be addressed. Within mutual trialogues between enterprise, employee representatives, and learning factory representatives, content-related focuses, learning environments, and teaching formats for the actual implementation are carved out (*Phase 1*). Thereby, requirements and suggestions can be identified which are not necessarily solely competence related, but also regarding enterprise processes changes. Thus, the participants will be met at their own viewpoint and they might be able to actively co-design their own work environment. Results of this phase are learning objective agreements and qualification plans. These are addressed and practical executed by qualification and sensitization measures within *Phase 2*. The content transfer is carried out in one or two day's workshops. Thereby, formal courses in classrooms as well as informal and practical sessions are conducted in the laboratory.

The didactic concept of the ACI learning factory comprises a variety of learning modules for industrial competences, focusing the development of IIoT competences. The contents of theses modules can be approached from the competence facets, a scenario perspective, or the content itself, in dependence from the learning focus. In this paper, the competence facet perspective is applied to illustrate the conveyance of *organizational*, *process*, and *interaction* competence.

In *Phase 3*, the conducted qualification and sensitization measures will be evaluated on behalf of qualitative as well as quantitative methods such as the evaluation approach for training programs [cf. 31]. Success and efficiency of the sensitization measures are considered following [32, 33]. This participative approach enables the identification of further need for action and self-reflection of the participants. Additionally, a fruitful basis for further mutual collaborations will be established within this.

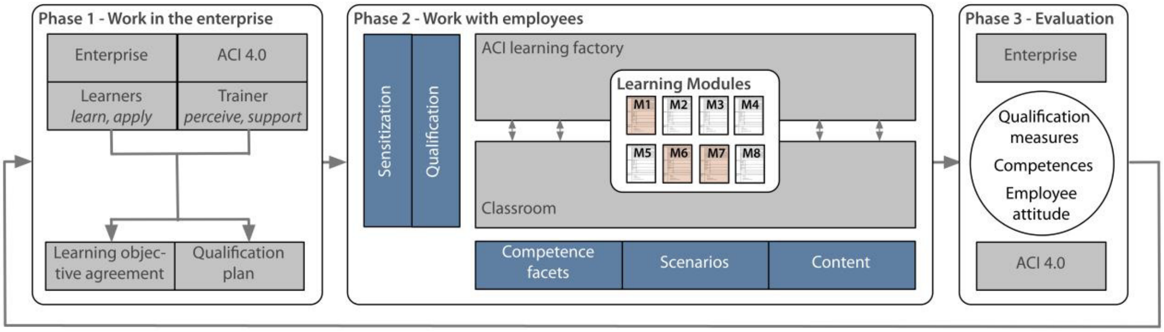

Fig. 1. ACI teaching and learning approach.

3.2. Learning modules for IIoT competences

The learning modules of the didactic concept are content-specific modules and consist of several learning elements. Within a learning module, the respective learning elements represent a content-related and thematic concretization of the module. Corresponding learning elements will be selected in dependence from needs, identified in *Phase 1*. From a competence facet perspective, modules focusing IIoT competences in the ACI learning factory are: (1) module organization competence, (2) module process competence, and (3) module interaction competence.

(1) addresses the requirement that employees have to cope with more diversified tasks which are beyond the classical organization of machines, employees, work pieces, or information systems. In the inner core, it is about the employees' capability to monitor and maintain the goal-oriented interplay of all relevant entities, which requires a new way of deployment. Work processes in the context of new IIoT technologies require a high degree of employees' self- reflection and voluntariness to proactively deal with new challenges. The module organizational competence enables the learner to develop the capability to self-reflect against the new tasks. Based on a potential analysis and a problem-oriented perspective, in which research skills as well as the transformation of new knowledge objects are focused, different organizational principles using diverse scenarios are exemplified. Representative examples are: decentralization of decisions, decision-making of technical entities, and task or process organization. Within this, alternatives of action are developed, tested, and reflected.

(2) addresses a sound understanding of process sequences and structures as well as their influencing possibilities. The focuses of this module lie in: perception of complexity and process changes, process evaluation, and, within this, the differentiation of important and less important processes. The employees will be enabled to assess the consequences of process modifications and to sense where which information and decisions are necessary. Additionally, the handling of IIoT technologies and their purposeful usage within the processes are core elements of this module. The learner experiences IIoT induced changes in a realistic production related environment. For example, advantages and limitations of centralized and decentralized process steering mechanisms are exemplified. Moreover, the learner configures and implements a CPS in the process according to necessary scenario-based process modifications.

(3) addresses an employees' ability to cooperate and collaborate with other employees, machinery and equipment, and smart work pieces via information and communication technologies and multi-modal human machine interfaces. Focal point is the goal-oriented inter related acting of all involved collaborators and cooperators. Especially, employees who are directly involved in the production process will be enabled to use collaboration and interaction media via their application and operation in different scenarios. The module enables employees to use new interaction technologies, to work in accordance to new interaction principles (emphasizing distributed working), and to reflect their own position as well as knowledge objects in the value-adding process. They learn to purposefully operate technical equipment. Thereby, the focus is on cooperation and collaboration with smart work pieces and machinery and equipment. Besides the machine demonstrators and work pieces touch screen displays, tablets and augmented reality glasses are used for this purpose.

3.3. Teaching and learning scenario

Starting point within the laboratory (Fig. 2) are different scenarios, which are either standardized from a predefined repository or an accurate simulation of the real processes where the employees (will) work (in the future). These scenarios can be merged to a whole teaching and learning scenario and are designed micro- and macro didactical. The simulated production processes, utilized work tasks and situations, to be used IIoT technologies such as wearables like augmented reality (AR) glasses or the usage of smart products, real-time feedback loops e.g. for logistics or machines have to be determined in dependence from the learning agreements. Within the scenarios, variable process structures are carved out for addressing *process* and *organization* competence as well as to integrate other learning content and methods. For addressing *interaction* competence, the scenarios comprise different kinds of collaboration and cooperation tasks between employees, employee(s) and machines, information systems or work pieces either directly or indirectly.

Fig. 2. ACI laboratory teaching and learning environment.

For the purpose of illustration, the scenario “add a priority lot to the production program” (Fig 3) from the scenario library is chosen. Underlying process is the production of femur prosthesis (This scenario represents solely a small part of the whole production process). They are usually produced in small numbers with a small range of variants. Some of these variants are provided with a powder coating that maintains a stable biochemical attachment to the bone. This process was chosen due to its high degree of generalizability. It can be applied independently of a specific product.

Initial trigger is the appearance of a priority lot order on the learners’ AR glasses. Within this, product specifications, due date, and instructions for necessary manufacturing process changes are provided. According to the product specifications, a small series of another product variant with powder coating needs to be produced. The specified due date indicates that this lot has to be executed as soon as possible. The process change instructions state that the learner needs to implement two new workstations into the current production process. One workstation (PCS) conducts the powder coating of the work pieces and another workstation the quality control (QCS) of the coating process. For this purpose the learner has to calibrate these CPS via a tablet and trigger their implementation in the current process flow. This calibration comprises the selection and composition of process- and product-specific programming and processing modules. However, when trying to implement the two workstations, the learner directly receives a notification on the AR glasses. A decision regarding further proceeding is required, as an immediate process change may lead to significant production efficiency losses. In case the learner is able to decide on the basis of throughput times, delivery date variations, occupancy times, degree of employment and OEE about the best time for discharging the old production lot, she is encouraged to do so (analysis on alternative actions is provided after the scenario). If the learner needs assistance for this decision, she is required to contact a decision competent employee via tablet. Another learner, a software agent or a trainer in the role of a production scheduler either represents this decision competent employee. In the present case, a prompt implementation conducted by the learner is the result of the consultation. In the meantime, a grinding station notifies another learner on her AR glasses regarding (a) refilling of lubricants and (b) that a grinding head (GH) needs to be replaced within the next 8 work hours. This requires coordination between the learners (A and B) due to a necessary intervention in the process. A verbal consultation between the learners leads to a quick process intervention for performing the refilling process. Additionally, learner B schedules the grinding head replacement. Triggered by the executed intervention, a group of currently manufactured work pieces (priority lot) notifies the learner on the AR glasses. They sense a planning conflict while approaching the workstation that is currently refilled. A decision whether they should approach another available but not intended grinding station is required. The learner checks the machine utilization plan via tablet and sends her decision as notification to the work pieces.

A continuous reversal of roles between the learners after such a scenario is a mandatory part of the concept. The trainer assists and supports the learner during the scenario execution. This provides the opportunity to (a) intervene in the process for a timely and action-oriented aid at any time and (b) a participative reflection of the action afterwards. Aforementioned enables the learner for an experienced-based gathering of new insights.

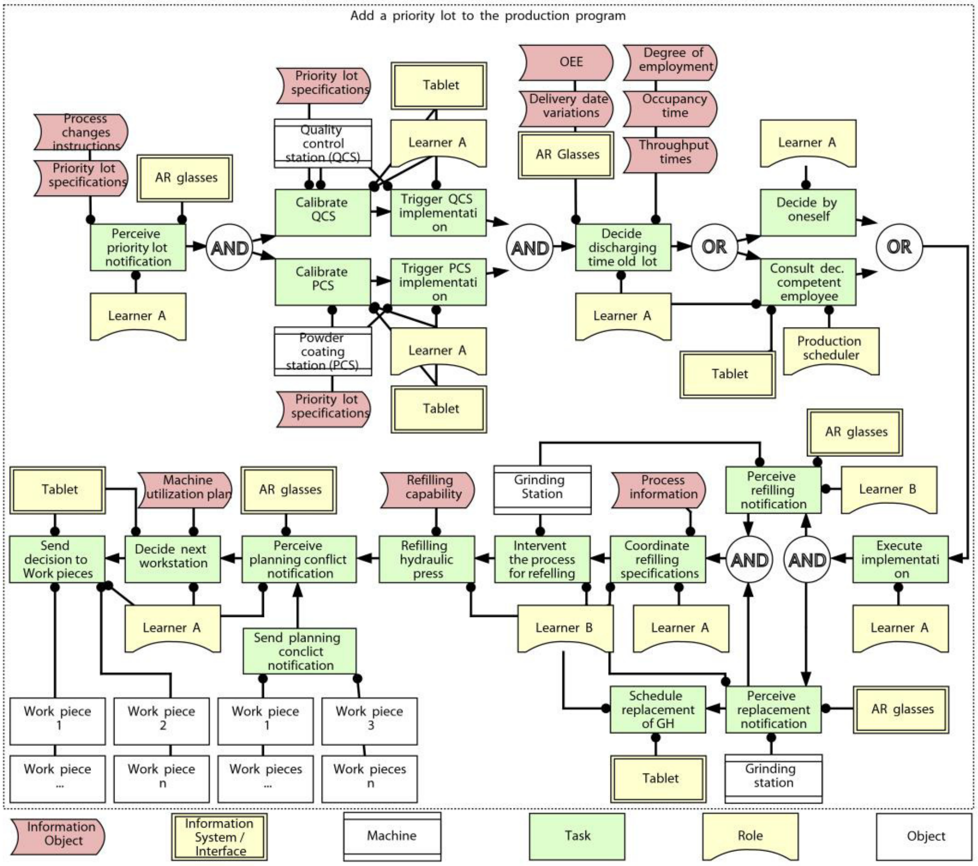

Fig. 3. Process model scenario “Add a priority lot to the production program”.

4. Conclusion and Outlook

The present contribution introduces a subject-oriented didactic concept for developing competences with an emphasis on Industrial IoT competences and technologies in the ACI learning factory. Within this concept, the learners' individual action problems are the key focus. Respective requirements and necessary competences, focusing on *organization*, *process*, and *interaction* competence, for Industrial IoT environments, were presented within this contribution. Furthermore, the learning modules for IIoT competences were introduced. The conveyance of IIoT competences in a teaching and learning scenario was exemplarily illustrated.

Current activities focus the completive implementation of the didactic concept into the laboratory as well as the continuous evaluation, reflection, and improvement of the teaching and learning workshop formats. Further tasks will be the development of additional scenarios and the integration of other IoT technologies.

References

[1] Palattella MR, Accettura N, Grieco LA, Boggia G, Dohler M, Engel T. On optimal scheduling in duty-cycled industrial IoT applications using ieee802. 15.4 e tsch. IEEE Sensors Journal, 13(10), 2013, pp. 3655-3666.
[2] Lee J. Smart Factory Systems. Informatik Spektrum 38(3), 2015, pp. 230–235, DOI 10.1007/s00287-015-0891-z.
[3] Broy M, Geisberger E. Cyber-physical systems, driving force for innovation in mobility, health, energy and production. Acatech; 2012.
[4] Kagermann H, Helbig J, Hellinger A, Wahlster W. Recommendations for implementing the strategic initiative INDUSTRIE 4.0: Securing the future of German manufacturing industry; final report of the Industrie 4.0 Working Group. Forschungsunion; 2013.
[5] Hirsch-Kreinsen H. Change of Production Work "Industrie 4.0" (in German). TU Darmstadt; 2014.
[6] Pfeiffer, S. Effects of Industry 4.0 on vocational education and training. Working Paper 15-04. IoTA. Austrian Academy of Science; 2015.
[7] Böhle F, Pfeiffer S, Sevsay-Tegethoff N (Eds.). Coping with the Unplannable (in German). Heidelberg: Springer; 2013.
[8] Wiesner F, Ullrich A, Vladova G. Competence Facets in the Context "Industrie 4.0" (in German). Working Paper WI-2016-01. Chair of Business Informatics, esp. Processes and Systems. University of Potsdam; 2016.
[9] Enke J, Kraft K, Metternich J. Competency-oriented design of learning modules. Procedia CIRP, 32, 2015, pp. 7-12.
[10] Abele E, Metternich J, Tisch M, Chryssolouris G, Sihn W, ElMaraghy H, Hummel V, Ranz F. Learning factories for research, education, and training. Procedia CIRP, 32, 2015, pp. 1-6.
[11] acatech (Ed.). Development Study "Industrie 4.0" – First Results and Implications (in German), Munich; 2016.
[12] http://internetofthingsagenda.techtarget.com/definition/Industrial-Internet-of-Things-IIoT, Retrieved: 2016-11-04
[13] Ganschar O, Gerlach S, Hämmerle M, Krause T, Schlund S. Production Work of the Future-"Industrie 4.0" (in German). D. Spath (Ed.). Stuttgart: Fraunhofer Verlag; 2013.
[14] Geisberger, E., & Broy, M. (Eds.). agendaCPS: Integrated Research Agenda Cyber-Physical Systems (in German) (Vol. 1). Springer; 2012.
[15] Lee EA. Cyber physical systems: Design challenges, In: Object Oriented Real-Time Distributed Computing (ISORC), 2008, pp. 363-369.
[16] Broy, M. (Ed.). Cyber-physical systems: Innovatios by software-intensive embedded systems (in German). Springer; 2011.
[17] Schirner G, Erdogmus D, Chowdhury K, Padir T. The future of human-in-the-loop cyber-physical systems Computer 46(1), 2013, pp. 36-45.
[18] Minerva R, Biru A, Rotondi D. Towards a definition of the Internet of Things (IoT). IEEE Internet Initiative, Torino, Italy, 2015.
[19] Atzori L, Iera A, Morabito G. The Internet of things: A survey. Computer networks, 54(15), 2010, pp. 2787-2805.
[20] Prinz C, Morlock F, Freith S, Kreggenfeld N, Kreimeier D, Kuhlenkötter B. Learning Factory Modules for Smart Factories in Industrie 4.0. Procedia CIRP, 54, 2016, pp. 113-118.
[21] Steiger H, Hartbrich I. "Industrie 4.0": We Need a New Work culture (in German). VDI Nachrichten, No. 29, 2014.
[22] Hummel, Hyra K, Ranz F, Schuhmacher J. Competence development for the holistic design of collaborative work systems in the Logistics Learning Factory. Procedia CIRP, 32, 2015, pp. 76-81.
[23] Erpenbeck, J., & Michel, L. P.. Competency-based quality securing of e-learning (CQ-E). In Handbook on Quality and Standardisation in E-Learning (pp. 125-141). Berlin Heidelberg: Springer; 2006.
[24] Erpenbeck J, von Rosenstiel L. Handbook Competence Mesurement (in German). Schäffer Poeschel; 2003.
[25] Clement U. (Ed.). Competence Development in Vocational Education (in German). Berlin: Springer; 2002.
[26] Abele E, Eichhorn N. Process Learning Factory – Training students and management for excellent production processes, in: Kuljanic, E. (Ed.) Advanced Manufacturing Systems and Technology. CISM, Udine, 2008, pp. 63-73.
[27] Tisch M, Hertle C, Cachay J, Abele E, Metternich J, Tenberg R. A systematic approach on developing action-oriented, competency-based Learning Factories. Procedia CIRP, 7, 2013, pp. 580-585.
[28] www.azi.lswi.de, retrieved 2016-11-07.
[29] Gronau N, Lass S, Fohrholz C. Hybrid Simulator – a New Approach for Production Management (in German). ZWF 106/4, pp. 204-208.
[30] Illeris, K. Workplace learning and learning theory. Journal of workplace learning, 15(4), 2003, pp. 167-178.
[31] Kirkpatrick DL. Implementing the Four Levels: A Practical Guide for Effective Evaluation of Training Programs: Easyread; 2009.
[32] Ullrich A, Vladova G, Thim C, Gronau N. Acceptance and Change Capability in "Industrie 4.0" (in German). In: Reinheimer S (Ed.) Industrie 4.0, HMD Praxis der Wirtschaftsinformatik: 52(5), 2015, pp. 769-789.
[33] Venkatesh V, Bala H. Technology acceptance model 3 and a research agenda on interventions', Decis Sci 39(2), 2008, pp. 273-315.