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Facing the demographic change – Recommendations for designing learning factories as age-appropriate teaching-learning environments for older blue-collar workers

Malte Teichmann[a*], André Ullrich[a], David Kotarski[a], Norbert Gronau[a]

[a]*University of Potsdam, August Bebel Str. 89, 14482 Potsdam, Germany*

Abstract

Digitization and demographic change are enormous challenges for companies. Learning factories as innovative learning places can help prepare older employees for the digital change but must be designed and configured based on their specific learning requirements. To date, however, there are no particular recommendations to ensure effective age-appropriate training of blue-collar workers in learning factories. Therefore, based on a literature review, design characteristics and attributes of learning factories and learning requirements of older employees are presented. Furthermore, didactical recommendations for realizing age-appropriate learning designs in learning factories and a conceptualized scenario are outlined by synthesizing the findings.

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Keywords: Learning factory; Vocational training; Learning environment; Age-appropriate competence development; Demographic change

1. Introduction

Demographic change and digitization are enormous challenges for companies. Following the approach of [1], "older employees" (OE) are defined as persons aged 40 or older who work in a company. They are often considered less motivated and less performance capable. A loss of cognitive abilities is also assumed [2]. These stereotypes are, however, not tenable from an empirical perspective [3]. OE are highly loyal and identify themselves strongly with their work [2, 3]. They, uniquely, possess a large extend of experiential [2] and tacit knowledge [1], leading to a high problem-solving capability in familiar contexts. Likewise, there is no strong correlation between biological age and job performance [3]. Through target group-specific training, job performance in certain areas (e.g., solving work place-oriented problems) can be increased [1]. In summary, OE' target group-specific potential can be leveraged through age-appropriate vocational training. However, OE, especially in blue-collar jobs, are among the more neglected vocational training groups [4, 5], and offers directly geared to their needs are rare. Often, training programs are aligned towards the job entry phase and, therefore, for younger learners. Learning objectives and learning content of interest to older workers remain unaddressed in them. Learning factories (LF) can address this challenge through a high level of practical and problem relevance in learning processes [6]. Successful competence development of OE depends strongly on age-appropriate teaching-learning settings. There are, however, no guidelines for achieving this. This paper aims to develop didactical recommendations for configuration of LF as age-appropriate teaching-learning environments for OE. For this purpose, the paper presents a framework for designing LF with different design characteristics and attributes (Sec. 2). Also, the learning requirements of OE are identified in the current literature (Sec. 3). Following this, we generalize didactical recommendations for implementing age-appropriate learning designs in LF by synthesizing the identified design characteristics and learning requirements (Sec. 4). The example of an age-appropriate learning scenario in a LF shows the possible practical application of the recommendations (Sec. 5). The article concludes with a short

* Corresponding author. Tel.: +49-331-977-3687; fax: +49-331-977-4612.
E-mail address: malte.teichmann@wi.uni-potsdam.de

conclusion and open research potential (Sec. 6). The article's goal is to outline design options for LF as age-appropriate learning environments and introduce OE' requirements into the scientific and design discourse of LF.

2. Design characteristics and attributes of learning factories

The landscape of LFs is quite diverse considering, e.g., framework conditions like ulterior motives, addressees, the share of virtual elements, real vs. simulated components, or didactical focus. According to Abele et al. [7], one of the two main objectives for LF is the effective development of participants' competences to become accustomed to complex and unusual situations. Against the background of current characterization approaches for LF, there are, however, no such aspects addressing the peculiarities of OE. Mainly, there are no didactical recommendations concretely specifying how to didactical design and implement learning processes of OE in LF: Wagner et al. [8] developed a classification system for LF based on the change enabler *universality*, *mobility*, *modularity*, *scalability*, and *compatibility*. This approach, however, solely focuses on technical aspects and neglects the particularities of learning subjects. Ullrich et al. [9] build on a subject-oriented didactic concept and outline that considering target groups specifics is critical for successfully convey competences in LF. Tisch and Metternich [10] point out several success factors of the methodological modeling approach in LFs (e.g., contextualization, activation of learner, etc.). All these approaches have in common that they (in)directly address learning subjects' specifics on a quite shallow level. Besides activation of learner, or target group specifics, or customized training there are no specifications on how to operationalize these categories. Abele et al. [7] developed a morphology, which is helpful to differentiate. Overarching features of LF are *operating model*, *purpose and targets*, *process*, *setting*, *product*, *didactics*, and *learning factory metrics*. The feature *didactic* comprises characteristics such as learning scenario strategy and several attributes like instruction, demonstration, closed scenario, and open scenario. A feature that directly addresses the implementation of didactic-conceptual design identified by [7] is *setting*. Further developed by Tisch et al. [11], promising characteristics are the learning environment and work system levels. Due to the design orientation of the setting and didactical focus, these characteristics can serve as a basis for developing didactical recommendations. Usable as a starting point for designing LF as age-appropriate teaching-learning environments, Table 1 summarizes the characteristics and attributes relevant for didactical design decisions in LF.

Table 1. Features, characteristics, and attributes of learning factories based on [7] and [11].

Feature	*Characteristic*	*Attribute*	*Brief description*
Didactics	Learning scenario strategy	Instruction	Instruction-based learning of work sequences
		Demonstration	Demonstrating existing processes, possible modifications, etc.
		Closed scenario	Highly structured with standardized events (e.g., normal production)
		Open scenario	Less structured with open events (e.g., malfunctions in a production)
	Type of learning Environment	Greenfield	Development of a new factory or new components
		Brownfield	Further development of the existing factory or individual elements
	Communication channel	Onsite learning	Learning within the factory environment
		Remote connection	Learning outside the factory environment with a connection to the factory
Setting	Learning environment	Purely physical	Production planning and execution is entirely physical
		Phy. w. virtual elements	Integration of virtual components (e.g., simulated machines or workstations)
		Purely virtual	Production planning and execution is entirely virtual
	Work system levels	Work place	Work places with different workstations (e.g., cutting and grinding)
		Work system	Production system with cooperating actors (e.g., different work places)
	Changeability of setting	Layout and logistics	Factory layout is changeable (e.g., machines and work places)
		Technology	Different technologies are implementable (e.g., mobile devices, machines)

3. Learning requirements of older employees

OE have often spent a lot of time at a workplace. Existing knowledge is successively expanded by performing the activity and solving associated working problems. Following this, learning content is selected according to the goal of improving the quality of the workplace (e.g., workplace relationships) [5, 12]. Learning content is also considered to be important if it is usable for solving relevant problems in one's work. Abstract learning content (e.g., methods), on the other hand, is viewed critically [2, 13, 14]. A significant change of learning goals leads to selecting learning content based on interests. These interests vary individually and can address both professional (e.g., expansion of specialized knowledge) and socio-emotional (e.g., strengthening position as knowledge carrier) goals [5, 14].

The learning behavior of OE is also changing. Unlike their younger colleagues, elders attach importance to a high degree of self-regulation in learning (e.g., individual learning speed) [2, 5, 12]. This also applies to learning formats, where older people rate a broad range of offerings positively (e.g., practice-oriented workshops, courses, learning in groups) [2, 5, 12]. Especially dialogue-oriented learning plays a relevant role in the learning behavior. Considering the self-image as carriers of professional knowledge and experience, OE are interested in learning with and from practitioners in the same field and in mentoring younger practitioners as well as in sharing their knowledge. Especially older professionals are interested in exchange with formal knowledge carriers (experts, trainers, teachers) to initiate educational processes [12, 15]. Building on prior knowledge and experience plays an important role in the complete learning process, too. Due to the decrease in fluid intelligence, OE find it difficult to learn new, previously unknown knowledge (e.g., a completely new language) content. However, the integration of similar knowledge content into prior knowledge (e.g., learning Italian with existing knowledge of the French language) is easier for OE [2, 12, 13, 14].

The change in individual learning behaviors affects the selection of learning formats. In addition to learning on the job (e.g., job enrichment) [5, 12, 13, 15], older learners in general benefit from fast applicability of new knowledge in a direct problem context. Learning success also increases with practice-oriented learning formats [2, 13]. The following formats provide a high level of problem and practical relevance in the LF context: job-oriented learning [6], augmented reality-based learning [16], and game-based learning [17]. Looking for the organization as the primary location to learn, OE often learn when it is not formally intended. For example, conversations at the workplace as a kind of informal learning can lead to new insights about the job [5, 13, 15]. Table 2 summarizes the identified requirements.

Table 2. Learning requirements of older employees.

Dimension	*Requirement*	*Specified requirement*	*Ref.*
Learning content	Workplace-related	Presented learning content should improve the quality of the workplace	[5, 12]
	Problem-related	Content needs a high problem relevance and contribute to solve work problems	[2, 12, 13]
	Individual interests	Content must address individual interests (e.g., professional, socio-emotional)	[5, 12, 13]
Learning behavior	Self-regulation	Older employees require a high degree of learning autonomy and self-direction	[2, 5, 12]
	Learn w. experts	Refreshing, rebuilding and expanding knowledge succeeds with formal experts	[12, 15]
	Learn w. colleagues	Knowledge exchange and learning processes succeed through learning with colleagues	[12, 15]
	Prior knowledge	Learning processes must build on existing knowledge and experience	[2, 13, 14]
Practice a. problem-oriented formats	Job orientation	Rapid knowledge application by adapting job characteristics increase learning success	[5, 6, 13]
	AR-based	Increasing the practical relevance of knowledge through augmented application	[16]
	Game-based	Applying game mechanism for re-contextualizing and consolidating knowledge	[17]
	Informal learning	Favoring knowledge exchange and learning processes through informal learning	[5, 13, 15]

4. Didactical recommendations for the age-appropriate design of learning factories

Synthesizing the features *didactics* and *setting* (Sec. 2) with the identified target-group learning requirements (Sec. 3) spans an analytical framework and enables systematic deduction of age-appropriate didactical design recommendation of a learning factory. OE choose learning content based on problem relevance and applicability in their work environment. Accordingly, a LF must be strongly adapted to real workplaces and processes to create a high level of practical relevance. Adaptation is possible through the acquisition and simulation of real production systems (e.g., machines, tools), simulation of (work) processes, and replication of work places. As shown in Figure 1, through adaptation, acquisition of new knowledge or skills in problem-oriented scenarios is possible.

		Learning content		
		Work-place related	Problem-related	Individual interests
Learning scenario strategy	Instruc-tion	Giving instructions to work in a modified virtual and/or physical LF-work system oriented in a real work system	Instruction to a solution path of a real work problem simulated on a physical and/or virtual LF-work place	Teaching relevant skills for real work places and/or systems in a physical and/or virtual LF-work system
	Demon-stration	Demonstration of the usage of new technologies in a virtual and/or physical LF-work system based on a real work system	Demonstration of possible solutions for a real work problem in a physical and/or virtual LF-work system	Demonstration of potentials of interest-driven work system modifications in a physical and/or virtual LF-work system
	Closed Scenario	Scenario-based simulation of a real work system with pre-defined learning goals in a virtual and/or physical LF-work system	Simulation of real work problems and pre-defined solution paths in a physical and/or virtual LF-work system	Conceptualise closed scenarios with pre-defined learning goals based on interests in a physical and/or virtual LF-work system
	Open Scenario	Simulation of a real work system with open learning goals in a virtual and/or physical LF-work system	Simulation of real work problems with open solution paths in a physical and/or virtual LF-work system	Triggering new learning interests with open scenarios in a physical or virtual LF-work system based on a real work system
Communication Channel	Onsite learning	Physical or virtual LF-environment oriented on/in modified real work places and/or work systems	Training of real work problems solution paths on/in a physical and/or virtual LF-work place and/or system	Providing a physical and/or virtual LF-environment with LF-work places and/or systems as open learning environment
	Remote	Remote control of the virtual and/or physical LF-environment from the real work place	Remote accessible training of real work problems solution paths on a physical and/or virtual LF-work place	Providing a physical or virtual LF-environment as remote accessible open learning environment

Fig. 1. Target-group oriented learning content in LF.

Adapting the LF to target group-specific learning behavior can increase learning success. On the one hand, scenario-based approaches are suitable for implementing the knowledge exchange that is important for older learners. On the other hand, LF must provide different opportunities for self-regulated learning processes. Learning possibilities must address acquisition, application, and recontextualization of knowledge. Figure 2 consolidates various options for facilitating target group-specific learning.

		Learning behavior			
		Self-regulation	Learning with experts	Learning with colleagues	Prior knowledge
Learning scenario strategy	Instruction	Providing self-regulated learning opportunities in a physical and/or virtual LF-work system	Giving instructions by formal experts on/in a physical and/or virtual LF-work place and/or system	Giving instructions by experienced colleagues on/in a physical and/or virtual LF-work place and/or system	Linking instructions in a physical and/or virtual LF-system to existing knowledge from a real work place and/or system
Learning scenario strategy	Demon-stration	Enabling self-directed experience in a physical and/or virtual LF-work system	Demonstration of modification opportunities for a real work system in a virtual LF-work system by formal experts	Demonstration of skills for a real work place simulated in a physical and/or virtual LF-factory environment by a colleague	Demonstration of knowledge-based improvements of a real work place on a virtual LF-work place
Learning scenario strategy	Closed Scenario	Enriching closed scenarios in a physical and/or virtual LF-work system with self-regulated learning opportunities	Experts as learning partners in a closed scenario with pre-defined learning goals in a physical and/or virtual LF-work system	Colleagues as co-learners in a closed scenario with pre-defined learning goals in a physical and/or virtual LF-work system	Designing closed scenarios with pre-defined learning goals in virtual LF-work systems based on prior knowledge
Learning scenario strategy	Open Scenario	Enriching open scenarios in a physical and/or virtual LF-work system with self-regulated learning opportunities	Experts as learning partners in an open scenario with open learning goals in a physical and/or virtual LF-work system	Colleagues as learning partners in an open scenario with open learning goals in a physical and/or virtual LF-work system	Designing open scenarios with open learning goals in physical and/or virtual LF-work systems based on prior knowledge
Communication Channel	Onsite learning	Preparing a physical and/or virtual LF-environment with opportunities for self-directed learning	Formal experts as learning partners in a physical and/or virtual LF-factory environment	Colleagues as learning partners in a physical and/or virtual LF-factory environment	Providing learning opportunities based on prior knowledge in a physical and/or virtual LF-factory environment
Communication Channel	Remote	Preparing a remote accessible physical and/or virtual LF-environment as a tool for self-directed learning	Formal experts as remotly accessible learning partners in a physical and/or virtual LF-factory environment	Colleagues as remotly accessible learning partners in a physical and/or virtual LF-factory environment	Providing a physical and/or virtual LF-factory environment remotely accessible on a real work place

Fig. 2. Learning behaviors of older employees in LF.

From a didactical perspective, the environment of LF ensures a high practical and problem-related relevance (Fig. 3.). This relevance can be further increased by integrating age-appropriate learning formats which apply to the factory itself (e.g., enriching scenarios with AR-technology). Stimulation is possible through additional learning formats that refer to the factory itself (e.g., serious games [17]).

		Practice and problem-oriented learning formats			
		Job orientation	AR-based	Game-based	Informal learning
Learning scenario strategy	Instruction	Contextualization of abstract knowledge on a physical or virtual LF-work place oriented on a real work place	Transforming abstract instructions of a physical LF-environment into applicable knowledge with AR-technology	Transforming knowledge of a physical or virtual LF-environment into applicable knowledge with serious games	Providing room to discuss instruction based knowledge learned in a real or virtual LF-work system
Learning scenario strategy	Demon-stration	Demonstration of abstract knowledge on a physical or virtual LF-work system oriented on a real work system	Transforming abstract knowledge of a physical LF-environment into demonstratable knowledge with AR-technology	Transforming abstract knowledge of a physical or virtual LF-environment into presentable knowledge with serious games	Providing room to discuss demonstrations realized in a real or virtual LF-work system
Learning scenario strategy	Closed Scenario	Designing job-oriented closed scenarios with pre-defined learning goals for a physical and/or virtual LF-work system	Enriching closed scenarios in a physical and/or virtual LF-work system with AR-technology	Enriching closed scenarios in a physical and/or virtual LF-work system with game mechanisms	Promoting goal-oriented communication sequences in closed scenario with pre-defined learning goals
Learning scenario strategy	Open Scenario	Designing job-oriented open scenarios with open learning goals for a physical and/or virtual LF-work system	Enriching open scenarios in a physical and/or virtual LF-work system with AR-technology	Enriching open scenarios in a physical and/or virtual LF-work system with game mechanisms	Providing open communication sequences in open scenarios with open learning goals in physical and/or virtual LF-work systems
Communication Channel	Onsite learning	Adapting characteristics of a real work place and/or system in a physical and/or virtual LF-environment	Providing AR-technology in a physical and/or virtual LF-factory environment for interaction with the learning environment	Adding haptic game mechanisms to a physical and/or virtual LF-factory environment	Enriching a physical and/or virtual LF-factory environment with communication opportunities
Communication Channel	Remote	Adapting characteristics of a real work place and/or system in a remote accessible physical and/or virtual LF-environment	Using AR-technology as a communication tool between a real work place and a virtual or physical LF-environment	Adding virtual and location-independent game mechanisms to a physical and/or virtual LF-factory environment	Promoting remote communication between factory experts and external persons in a virtual LF-environment

Fig. 3. Practice- and problem-oriented learning formats in LF.

5. Exemplary conception of an age-appropriate learning scenario

This learning scenario is being developed in a cooperation between a physical LF with virtual elements [9] and a medium-sized producer of windows in a research project. The international competition led to an innovative window that is ventilated and soundproof even when closed. The production process requires the preparation of the frame and the installation of a ventilation system. The new product requirements lead to a modification of the production line (e.g., buying a new CNC-milling machine and an assembly station). The long-term employees have little experience in the instruction-based assembly of technical systems. They need to learn the steps to prepare the window frames on the CNC machine and install the ventilation system on the assembly station. The scenario aims at a high job orientation by simulating real work places in the factory environment, self-regulated learning processes, and practice-oriented learning. Fig. 4 shows the connection between the LF and the recommendations.

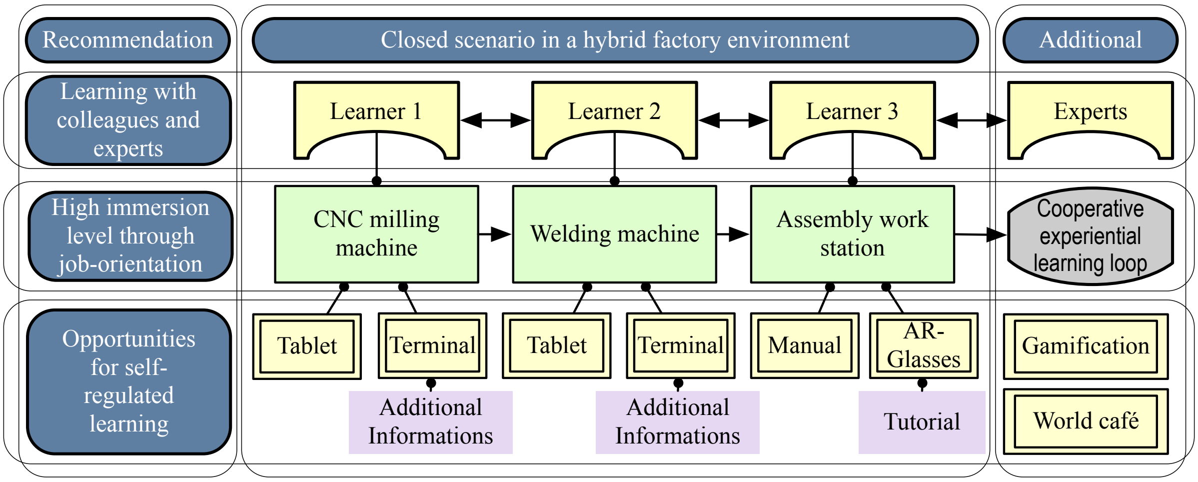

Fig. 4. Conceptional connection between a hybrid learning factory and the identified recommendations.

The LF consists of a changeable layout with various physical demonstrators (DM) and workpiece carriers (WC). The DMs, connected by a conveyor system, enable the simulation of real work places and/or work systems. The use of configurable (touch-)screens on DM and WC, loudspeakers, and machine terminals generate a high immersion level. AR-technology is integrable as well. To further increase the proximity to the work place, we plan to use immersion-enhancing technologies (e.g., gloves for haptic- and masks for olfactory feedback). The LF-work system is configured based on the window manufacturer's work system. For simulation of the work system, we replicated the CNC milling machine, welding machine, and assembly work station with images, video, and sound. In addition, CAD models of the intermediate products (e.g., parts of the window frame) and components of the technical ventilation system (e.g., cabling, motors, etc.) will be created. Video and audio material of the existing user interfaces of the CNC milling machine and the welding machine were transferred to the (touch-)screens of the DM. Within the scenario, machining the simulated workpiece at a DM leads to a change in completion level. The WC display the simulated window frame as a CAD model on the screen according to the degree of completion.

The scenario itself will offer various opportunities for self-regulated learning. The learners can repeat all steps at the work system and the different work places (e.g., welding the window frames) without time pressure. Using AR-technology, achiving a high practical relevance to learning processes at the simulated assembly station is possible. For this purpose, AR-supported tutorials will be developed based on the CAD models, the analog assembly instructions, and interview transcripts of already trained employees and implemented in a learning and tutorial system. Equipped with AR-glasses, the learners can learn assembly steps (e.g., laying cables, positioning motors) on a 3D model of the window frame in three-dimensional space. The conception process will take potential technology acceptance problems of OE into account, too. The AR-solution presented must therefore be accessible at a low level. This means easy usability and seamless technical integration into the LF environment. Various technologies (e.g., tablets, analog manuals, etc.) provide additional information for each work step. Experts from the learning factory are also available to assist with demanding work steps (e.g., programming the CNC milling machine). The realization of cooperative experiential learning can address collaborative learning processes in the scenario. For this, one participant learns at one workstation. A change to another workstation follows this until all participants have learned at each workstation. The learners then discuss their learning experiences in expert moderated reflection formats (e.g., word café). By consolidating the different perspectives on the learning object, learners can, for example, better understand work steps and thus increase their ability to act [18]. The integration of serious games is also possible to consolidate the learning content [17].

6. Conclusion

LF configured based on learning requirements of OE can be transferred to age-appropriate teaching-learning environments. In particular, LF with changeable layouts achieve the practical relevance for OE by configuring the factory environment based on real workplaces and systems. Opportunities for self-regulated and collaborative learning must be available regardless of a physical, virtual, or hybrid learning environment. To address a high level of problem and work relevance of the presented content, orientation towards individual learning reasons is essential. This goal is achievable through a subject-oriented perspective [18]. A prerequisite for this is the equal positioning of individual competence development needs and company qualification requirements [4]. In addition to the practical implementation of learning processes in an age-appropriate learning environment, organizing vocational training is also essential. It is assumable that current vocational training efforts structurally exclude OE. Age-appropriate learning offers in LF contribute to providing age-appropriate vocational training opportunities that have been lacking up to now. From a structural point of view, on the other hand, decision-makers need a better understanding of the valuable resource of OE. LF designed as collaborative teaching-learning environments can also contribute to cross-generational and cross-competence understanding. For example, cooperative learning scenarios between experienced blue-collar workers and white-collar workers are conceivable. Beyond the scope of vocational training, the role of LF in the transition to retirement or in the retirement of OE remains open. In particular, the disappearance of long-trained skills and experienced-based experiential knowledge from operations due to OE retiring further exacerbates skills shortages. In perspective, this makes the conversion of knowledge and its transfer to younger employees important. Participating in the content creation of a LF (e.g., learning scenarios) could be a starting point for saving OE' knowledge.

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