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Intelligent learning management by means of multi-sensory feedback

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Abstract

Along with new manufacturing paradigms such as Industry 4.0, based on cyber-physical systems or ubiquitous manufacturing and the rapid development of underlying technologies, the importance of lifelong learning as an integrated part of the overall activities within manufacturing companies increases. Herewith, a holistic learning culture and modern learning environments are required. To allow the learner to independently acquire knowledge and skills in a learning factory an intelligent learning management system and extensive feedback information to the learner are needed. A central approach is to pursue the new interactive knowledge transfer through the multi-sensory approach combined with innovative feedback processes, enabling a learning process with all human senses.

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Keywords: Learning management system; higher education; engineering didactics; learning factories; multi-sensory observation; energy and resouce efficiency

1. Introduction

A holistic learning culture in modern learning environments such as learning factories provide the potential to develop key competencies and the capacity for critical reflection [1]. Learning factories provide a realistic virtual and/or physical model of a factory that can be combined this with selected methods of teaching to an action-oriented teaching and learning environment [2, 3, 4]. Specific knowledge, skills and abilities can be trained by learning factories, which are needed for performing well in jobs, so called key competencies [5]. A method which supports a deep understanding of relationships and closes the theory-practice gap is critical reflection [6]. It is defined as “a conscious and systematic approach to thinking about experiences with the aim of learning and changing behaviors.” [7] Hence, enabling informal learning through trial action. Informal learning means that the learning process is learner-driven and self-regulated by the learner [8] and that it is independent from trainings and development organized by organizations [8]. In the context of the learning factory the learner learns from himself/herself through learning by doing. In addition to the transfer of knowledge, learning factories are in particular suitable for the acquisition of vocational knowledge and skills. In fact, this learning factories will change the learning culture. That means a change in values and expectations concerning the relevance of learning in organizations. It could be manifest in organizational infrastructure as well as in behavior and beliefs of the employees [9]. The added value of a truly self-initiated learning process, as described by [6, 7, 8] is becoming an integral part of the current learning culture [10, 11, 12]. To allow the learner to independently acquire knowledge and skills in a learning factory, an intelligent learning management system and extensive feedback information to the learner are needed. Intelligent learning management systems implies a computer-directed system that is able to evaluate individual learning processes to allow (semi-)automated controlled learning processes. Thus the computer system adapts the individual learning speed of the learner. For this purpose, the learning factory must be equipped with appropriate sensors and

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actuators. Existing concepts and implementations of learning factories have herein deficits. To close the gap between learning factory training and operational practice, the authors introduce the concept of an intelligent learning management by means of a multi-sensory learning factory environment. A central objective of the presented approach is to pursue the new interactive knowledge transfer through the multi-sensory approach of the learning factory combined with innovative feedback processes. The multi-sensory approach is aiming at a learning process with all human senses.

2. Sensory perception in learning systems

Learning factories can now be considered as a recognized method of appropriation in production-related skills and content [13]. The vast majority of learning factories investigated by Micheu and Kleindienst are representations of a realistic factory, existing in the form of real assets [14]. Only in a few cases, simulations are used for imaging of individual production processes or equipment complement. The existing learning factories thus appeal particularly audiovisual sensory channels at a high level of abstraction. From the standpoint of psychology, we know however that learning with all senses leads to faster and more sustainable learning outcomes [15, 16].

Here, the learning process should not only be regarded as a one-sided mental stimulation with an impact on the actions and behavior, but as an interaction between body and mind. The concept of "embodiment" supports the view that active learning through various postures has an impact on the perception or the judgments and feelings and hence has a positive effect on the learning success [16].

Concerning the didactic orientation, different priorities can be observed, from which particular approaches such as problem-based learning [12], action-oriented learning [17] and experience-based learning [18] stand out. Although the existing literature sporadically mentions role playing and simulation games as a supplement to learning factories [8, 19], there are so far no concepts or practices that base learning factories consistently on the methods of a game-based learning concept. An initial proposal for a competence-oriented curriculum as a teaching model for describing a learning factory is proposed by Abel et al. [20]. Due to the lack of study data, however, it is currently impossible to make any reliable statements about beneficial approaches and their goals.

3. Multi-sensory feedback as means for an adaptive learning management

The learning factory at the Technische Universität Braunschweig is part of a comprehensive concept under the name "Die Lernfabrik" (see www.DieLernfabrik.de). A part of this is the so-called "experience lab" - a physically scaled model of a real factory process chain, realized by so-called modular production systems. The model-scaled system makes it possible to replicate system dynamic effects of the real-sized system without jeopardizing the learner (for example, by high forces or high voltages) [21]. Currently, only simple monitoring and control capabilities of the system are available, which are a basis for a systematic development.

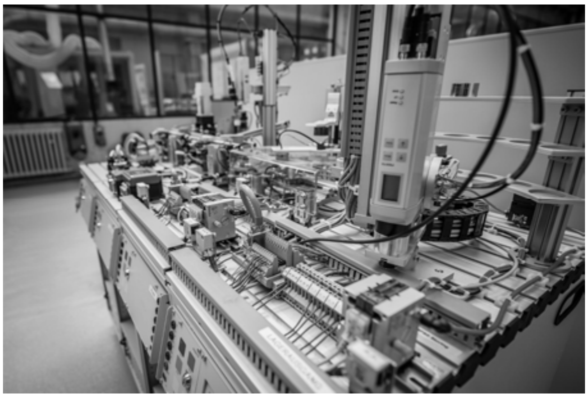

Fig. 1. Four exemplary modules of the experience lab process chain setup.

Likewise, an involvement, on the site of existing, renewable energy sources is possible, for example, to take into account the volatile availability of alternative energy sources in real scale. Semi-finished products can be generated by fuse deposition modelling (3d printing) and final products can be recycled eventually to create new filament for 3d printing with secondary materials. The utilized means for value stream analysis and assessment are in the current learning factory (as well as in industrial training sites) mostly limited to purely visual sensing (e.g. reading of metrology and metrics dashboards).

Hence, only a small fraction of the relevant thematic content can be displayed and only a small part of the human sense channels is utilized properly. A central objective of the research work is therefore to pursue new interactive knowledge transfer through the multisensory approach in the learning factory combined with innovative feedback processes.

3.1. Sonification and human sense utilization for machine condition monitoring

The multisensory approach of the research project addresses learning with all human senses through the use of sensors and actuators within machines. At this the authors were inspired by the idea of the sonification process monitoring introduced by Hildebrandt et al. [22] and by the full utilization of human senses for medical diagnostics, where the patient's physical health state was tested by using as many human senses as possible. The IPPAF scheme describes the visual inspection (I), the palpate inspection (P), the percussion inspection (P), the auscultation inspection (A) and the functional test (F). The holistic use of human senses for condition diagnosis is to be transferred to the production domain for products and machines. An example where this inspection scheme was already applied to machines was for internal combustion engines for ships or cars until the late eighties, when the distributor and carburetor where purely mechanically controlled and driven components. The mechanic or the experienced owner of the car could hear, feel and simply sense how well the engine was running and was able to evaluated changes done to the mechanical control system by the same senses. For example, by listening for disharmonies in the engine strokes the expert directly got aware of his need to act. By slightly adjusting control parameters, e.g. the distributor angle, the harmony could be readjusted and the system became stable again. This idea is to be transformed to modern production machine, e.g. by Sonification.

Innovative feedback mechanisms as shown in Fig 2 are to be used to make complex relationships more accessible to the learner. This approach goes beyond the often utilized abstract visual and audio feedback (such as the conventional display of performance indicators on computer monitors or emission of beep noises). Sonification as an immediately perceptible approach which is explored by including sounds and familiar acoustic emissions as feedback on the state of machine tool health.

3.2. Products with intelligent feedback mechanisms

At this point of view, the research work also includes the development of an intelligent product, as a substitute for the currently found simple products in most learning factories. The product is intended to gather information about its individual production process and make it accessible for the learner for a straightforward analysis. This includes aspects such as production quality, the specific energy input as well as the specific lead time. For this, the existing simple products are enhanced with appropriate information and communication technology and memory functions.

By closing the loop of the physical system, extracting state information and feeding it into the virtual image of the environment to interpret the applied changes in order to generate control parameters to manipulate the learning environment, a cyber-physical system is created, as described by the term *Industry 4.0*. *Industry 4.0* is therefore utilized as a means for more effective learning.

3.3. Benefits to the learning experience

The multisensory approach combined with innovative feedback processes are to permanently increase the motivation and satisfaction of the learner. In addition, the independent and autonomous capacity is enhanced by experiential knowledge through performed actions and self-organization of the learner [23]. This is called experience-lead, motor-manual learning [24] with reflection through feedback which is being put out directly from the learning factory setup in form of multi-sensory feedback. These acquired capabilities allow the learners to organize themselves and cope with open problem situations [23].

3.4. Gamification as an instrument for learning management

The expansion of the existing didactic concepts in learning factories is extended to approaches of game-based learning, by means of a simulation game. The physical and the virtual factory model are created and supplemented by additional parameters to incorporate economic and social aspects [25].

Currently the experimental factory of the Technische Universität Braunschweig specializes in production and systems engineering and is included in the curriculum of the lectures *Energy Efficiency in Production Engineering* and *Sustainable Cyber Physical Production Systems*. There, the students learn to detect energetic interdependencies in linked production systems and to analyze and identify potential improvement measures. They ought to implement and evaluate most promising technical and organizational improvement measures. However, so far no evaluation studies have been carried out (for example, comparison of the exam scores before and after the use of the learning factory). However, the student supervision is time consuming and requires a comprehensive preparation of current learning factory system setups in order to compensate existing deficits or learning progresses of individual students. Reasons for these existing differences in learning progresses within learners' groups are based on age/experience differences, different educational backgrounds, language skills, and others. These influencing factors are to be compensated by an intelligent learning factory to ensure a truly harmonic learning experience for the whole learners group.

To evaluate success factors, the evaluation concept of the learning model factory provides in a first step to carry out a learning level measurement at the beginning of the learning process in order to assess the growth of knowledge at the end in the form of a knowledge test (or in a university context an exam). This process is complemented on the other with a comparison of the learning outcomes of control and experimental groups. As a suitable control group, students could be used who learned with the conventional learning factory setup and students who attended only a classic lecture, where the professor teaches the learning content by the help of a black board in classrooms.

4. Concept of the intelligent learning factory

The aim is, as part of the learning factory efficiently and cognitively diverse align learning and complementing useful with a didactic approach. Based on the training factory in existence on the IMF intelligent teaching-learning environment using the example of the topic energy and resource efficiency will be designed, which can be used independently by the learner and those supported on the basis of feedback methods for adaptive learning control interactively in his individual learning process. Iterative, the operation of this modified Model Factory is scientifically evaluated. Starting from the overall concept of the "*intelligent learning factory*" (see Fig. 3), the following development objectives are described in detail in the following sections:

- Energy and resource efficiency
- Intelligent product
- Feedback mechanism

- Learning success measurement and control
- Learning management system

4.1. Energy and resource efficiency

The *intelligent learning factory* to be developed aims thematically on the issue of energy and resource efficiency in production and thus addresses a knowledge- and technology-intensive industry that requires in particular a highly interdisciplinary and process related knowledge. The objective is to extend the existing learning factory setup shown in Fig. 1 to incorporate the aspects of energy and resource efficiency as well as inhomogeneous learning group compositions. For this, the methods and concepts of energy the resource efficient production are transferred into the curriculum of the learning factory and implemented in both the physical factory setup and the virtual factory model. In conjunction with the technical development of the learning factory it will be ensured that the methods to be exercised both, on process level and on overall factory level, will lead to realistic cause-effect phenomenon.

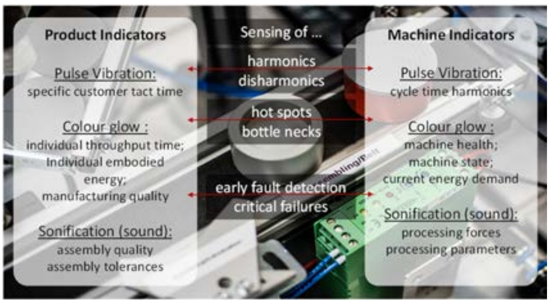

Fig. 2. Extension of the human senses for product and process analysis.

This is the only way, the transferability of the acquired knowledge from the model factory to the real factory in daily work use cases can be realized. The development work has hence interfaces to the development of the physical components of the intelligent learning factory, the virtual simulation model, as well as the adaptive learning management system.

4.2. Intelligent product

In modern production systems, the critical process and product characteristics in regard to energy and resource efficiency, are for humans only indirectly perceptible. Energy flows within manufacturing processes and machines are not simply accessible from the outside perspective and hence provide no direct information to elicit the need for action and improvement. Within this research work, the authors aim to develop an intelligent product that provides the learners plenty of useful information about the production processes while passing through the process chain. Most important performance indicators are specific energy demand, individual cycle times and quality of the performed operation.

4.3. Feedback mechanism

An efficient learning process requires suitable methods for adaptive control of the learning process. In particular, this includes the feedback to the learner. As part of this concept should be innovative concepts designed to appeal to learners holistically. For this purpose, stress sensors, user input evaluations and position tracking of the learners within the learning environment are to be used to track the learners' individual motivation, progress and ability to be further challenges by additional extraordinary tasks. Also team and role-specific performance and dynamics are planned to be tracked and evaluated to create a better learning environment.

4.4. Learning success measurement and control

The success of a learning factory is measured primarily on learning success of their users. Particularly, the development of competences from the learner. This includes self-competence, which helps to develop new goals and to act creative, professional and methodical competences, which help to learn new things and methods as well as social competence which allows the communication of learning gaps and active reflections in contrast to other learners. Therefore, it is important to evaluate the process and results [5]. According to Kirkpatrick, there are four levels of success control, named learning success, satisfaction success, transfer success and business success [26, 27].

Therefore, the aim is the implementation of appropriate learning measurements in order to evaluate the advantages and disadvantages of such a solution. First, all measurements are considered with a sample of students. Afterwards, employees are observed in the intelligent learning factory during training sessions. As part of the transfer measurement it is checked, whether the learners are capable to fulfill the same optimizations within the real production processes as in the learning factory. The transfer measurement evaluates the application of acquired knowledge to new and slightly other problems as part of a job or a service training. It is the target to evaluate the usefulness and practicability of the newly created teaching-learning environment.

Besides the transfer measurement, it is possible to examine which group of learners profits most: older or younger learners; women or men; learners with different levels of knowledge. Furthermore, the metrics are to be developed to evaluate the real system and the virtual simulation model. The metrics include both a performance measurement system for the methods of the modular "energy and resource-efficient factory" as well as system-internal indicators for evaluating the individual learning progress of the learners. Relationship diagrams between the indicators are used as a basis for adaptive control of the learning management system as well as to link the simulation-narrative for event control to the model. Innovative and new indicators measure the progress and learning stress of the individual participants by body stress sensors known from fitness applications.

This approach will allow an evaluation of the learning progress and knowledge transfer results [5]. To measure the growth of competences and the transfer, established scales are used like the German version of the *Learning Transfer System Inventory* [28] or the *Competence Reflection Inventory* [29] as well as the self-description of the learners [5] as a pre-post intervention with a follow-up six month later.

4.5. Learning management system (LMS)

The adaptive LMS provides the interface to the individual learner and the virtual image of the factory environment. Depending on the learning objective of the composition of the learners, the degree of complexity of the game situation (gamification) is selected by variable scenarios which are mirrored on the virtual model in the learning environment.

Due to the heterogeneous composition (knowledge, capacity, motivation) of learners an individual learning progress will settle within the group of learners during the classes or seminars.

This individual progress must be recorded and evaluated by sensory means (e.g. stress sensors or behavior tracking) and by tracking the feedback behavior (inputs and actions within the physical system). Depending on the detected individual learning progress the role-based complexity of the business game situation is adjusted by the adaptive learning management system. This way, the individual learner may be appropriately encouraged and promoted. Part of the means of communication with the learner to encourage, remediate and promote him or her is a client application for learners to record their learning progress and to lead the learner through a simulation-narrative.

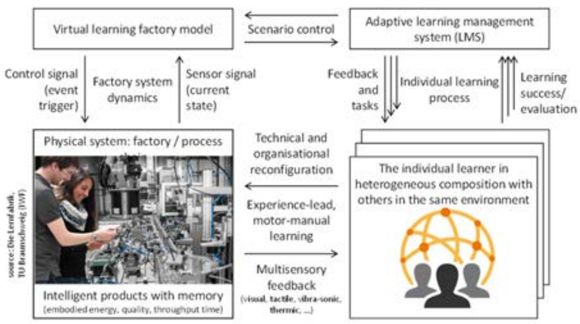

Fig. 3. Concept of the intelligent learning factory

The game-based-narrative is developed taking into account the methodological toolkit and the implementable technical and organizational measures of the physical setup. The narrative puts the learner in the situation of a realistic industrial environments. Featured contents of the narrative are the real production reference as well as the possibility of a role reversal (change of perspective).

The teachers are thus given conditions to carry out a situation-based selection of scenarios within the learning environment and the composition of the learners (by role reversal). The scenario-based triggering of events can enable externally controlled conditions (for example, customer requirements, economic developments and technical failures) on the learning system. The simulation images the physical production setup as well as the virtual surrounding (factory building, technical building services, supply chain, customers, suppliers and extensions of the production setup) world, thus enabling a virtual-driven broadening of horizons in the game situation. The realistic narrative ensures that a transferability to industrial work environment is carried out by the learner.

5. Implementation in industry and academia

The requirements and research objectives have been derived directly from the requirements of industrial and academic applications or training facilities. In the requirements analysis it was the target to derive the specifications of innovative, alternative teaching and learning systems. The requirement specification is carried out for two demonstrators: automotive industry (car body assembly) and university teaching (energy efficient production systems). The related requirement management is done in the known V-model of a development processes in order to respond to the formulated requirements and objectives of the stakeholders during the entire duration of the development project. Central objective of the university teaching case is to educate engineering students from different engineering disciplines and skill level in one common learning-teaching environment at their individual load level without compromising the necessary load on the teacher. A better perceptivity of the learner is to be achieved by a multisensory feedback and a scenario-based adaptive learning objectives. In the industry case the change of roles, the demographic change and the differentiated skill and motivational levels are addressed primarily. By individual learning objectives and adaptive complexity levels of individual or group tasks, an interdisciplinary communication and is fostered and targeted in extension to the targeted outcomes of the university teaching case. Subsequently, the implementation of research and development results in the industrial and academic learning factory environment is done in parallel. The subsequent application and evaluation in the demonstrator environments will also be carried out separately with participant groups from industry and with participants from university (students).

6. Outlook

Within the paper the authors present a general framework and approach of an adaptive teaching and learning environment for industry training and academic engineering education. Within the publically funded three-year period of the research project this approach will be further detailed, finally developed and designed as a functional software/hardware prototype. The functional prototype system will be tested with an industrial and an academic test group and will be benchmarked with reference groups using conventional teaching and learning systems for the same task. In succeeding publications, the development steps and intermediate evaluation results will be described in detail. In the end of the funded research project it will have to be proven to what content the competencies of the learners could be improved with the same or shorter periods of time and could be retained long-term in comparison to the reference groups. The better learning experience is evaluated by practical test immediately after working with the learning factory and after six months, in which the knowledge or new skills have to be adapted in a similar action and problem areas. Both, skills acquisition and expansion, as well as transfer quality can be assessed. At the same time the effort for teaching and the supervisory intensity will have to show to be reduced significantly. The industrial application case represents, in contrast to the academic engineering education case, a far more difficult setting, as the learners' composition is particularly more heterogeneous. This includes the age, the educational background (skill level), level of expertise and rank or role. The diverse features make it possible to try out the intelligent learning factory alone as well as in support for the individual learning rate (different level of knowledge), different learning types of the users (haptic, visual and auditory) and several target groups (older user, women in technical jobs, non-native speaker). The intelligent teaching-learning system will be able to address all learners within this heterogeneous composition in one class at the same time.

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