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Promoting work-based learning through Industry 4.0

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Abstract

To efficiently support ramp-up processes as well as the instruction of new employees in industrial production, increasing the integration of working and learning is one promising approach. In this context, cyber-physical systems in Industry 4.0 enable the creation of work environments with new opportunities to purposefully facilitate learning new tasks. Corresponding measures make use of the large available amount of real-time information and pre-processed production data. The informed selection of appropriate measures has already to be considered in the early planning stages of a production system. Thus, the specific suitability, effectiveness and operating efficiency of work-based learning solutions have to be quantified in advance. This requires an empirical investigation and evaluation of the particular influence in an authentic production setting. The Demonstration Factory of the RWTH Aachen Campus offers an ideal framework for this purpose. It features the real production of marketable products as well as an infrastructure tailored to experiment-based production research.

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1. Introduction and motivation

Due to increasing complexity and dynamics of products and processes, employees in today's production have to be qualified for more than just repetitive operations. The development of problem solving skills to autonomously deal with failures or completely new tasks is getting more and more important. At the same time, the ongoing individualization of products in industrial mass production poses new and major challenges on the qualification of production workers. [1]

Because of no or only few repetitions of the individual production step, it is not reasonable to just reproduce and practice it. In addition, transferring externally learned content to the requirements of the work place is usually associated with enormous losses [2]. In this context, work-based or work-integrated learning is a suitable approach as it takes place directly in the working environment [3] and dealing with real work tasks [4]. In doing so, the learning content is immediately connected to needs and applications of daily work [5]. Thus, the motivation to learn as well as recalling the acquired knowledge is supported [2].

At the same time, the current development towards Industry 4.0 is closely linked to the emergence of new and the enhancement of existing technological solutions that, beside extended opportunities to control production, also provide chances to promote work-based learning. Concerning this matter, it is necessary to tap the full potential of cyber-physical systems and the internet of things within socio-technical industrial production systems. To achieve this goal, novel approaches for work-integrated qualification of production workers are needed. Instruments for the implementation of corresponding learning methods have to be developed as integrated components of the new socio-technical systems. Mainly sensorimotor assembly work tasks will be addressed in connection to ramp-ups of new products, teaching new workers or rare work tasks which however have to be done fast and reliable.

The paper at hand points out how key requirements for learning in production are fulfilled by means of central characteristics and technologies of Industry 4.0. Additionally, corresponding examples of practice are introduced. In combination with a new approach to empirical validation, this forms a holistic model supporting

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an economically optimal implementation of work-based learning in industrial production systems.

2. State of science – What makes work conducive to learning

There are manifold influences on learning in production environments. On the one hand, these influences refer to the current task and learning methods. On the other hand, the working and learning persons are determining factors themselves [6, 7]. While basic personal characteristics of the employee may not be influenced directly and product properties as well as certain process requirements are also given externally, efficiency and effectivity of learning can be positively affected by an adequate design of the work system. In literature, a variety of criteria for work design conducive to learning can be found, which are mostly derived from general human learning mechanisms. In general, learning environments are considered to encourage learning if they are realistic, situated, complex and problem-oriented. In the case of work-based learning, this is widely given anyway, but supportive measures enable a more effective utilization in this regard [8].

Concerning support for learning at the workplace, moreover, self-directed working and learning are postulated [4]. The basis for self-directing is the ability to control and correct work results autonomously [9]. To enable the unaided use of learning content by the employee, in many cases learning by instruction is already replaced by self-directed acquisition of knowledge and skills, constituting intrinsic motivation to learn at the same time [2]. Above all, any learning activity is based on information. If it is not already available from the process, the active provision of information is also a key prerequisite [10].

3. Work-based learning – Goals and levers of supportive measures

The basis for efficient work-integrated learning is a design of the work system that is conducive to learning. This enables the development of otherwise largely untapped competence potential, which could not be addressed adequately in learning situations outside of work [11].

To study human learning in production, assembly systems with a large amount of manual labor offer an appropriate environment as the role of human workers and their qualification is of particular importance. The technical and organizational arrangement strongly depends on the directly influencing factors of an assembly, which can be divided into “product, process and personnel” [12]. In relation to the product, its version number, size and number of installed parts are crucial variables. Important parameters of the process are lot sizes, quantities, degree of automation and complexity. The production factor personnel can be described mainly by its age, language, skills and learning type. Fig. 1 shows the basic interactions between these influencing factors and technical as well as organizational levers affecting the process of work-based learning.

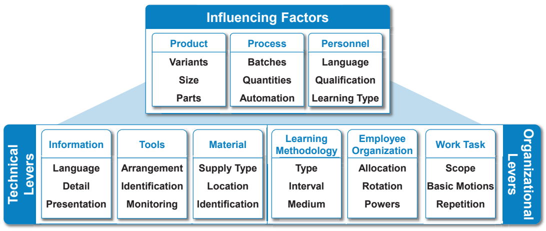

Fig. 1. Influences and levers affecting the process of work-based learning

The technical levers can be divided into the provision of information, tools and material. For the employees, the information has to be displayed at the right level of detail, the appropriate language, the best way of presenting and the adequate medium which allows them an optimal absorption [13]. Tools are to be regarded as the next important lever, which also comprises several informational aspects. Beside the arrangement manner, the identification of the required tooling equipment and monitoring the use are important components in this regard [14]. The material in terms of parts to be installed also has a significant impact on the design of the work environment, where in this case the deployment strategy, the mounting position and also the method of identifying parts are important.

Regarding work organization, a compliant learning methodology, staff organization and the work task represent central levers. Depending on the learning type of the employee (auditory, visual, communicative, motor), the best method using a suitable medium at the right time has to be applied [15]. The targeted assignment of personnel and the organization of rotation and allocation of powers also have a major influence on the level of qualification [16]. The task itself is the final component of organizational measures – the scope of the activity, the number of contained basic movements as well as the frequency of repetition are crucial in this respect.

The specification of levers has to meet the requirements of the specific framework that is defined by the influencing factors. One example is the adequate selection of media for work instructions. Empirical studies have shown that for low variance an instruction in text form is sufficient – for high variance, using at least a picture or even an animation is more advisable [17]. Since this would have to be shown on an appropriate medium, this is a monetary overhead (creating animation, software, etc.) compared to a text-based solution. Thus, the specific effects of each measure have to be quantified and confronted with the investment in order to assess it economically and to find the best suitable solution. Using the given example for learning in a high variance assembly, a company employs one industrial engineer (90.000€) just to transfer drawings into animations with a specific software (5.000 € license) and 5 workers would have a tablet (200 € each) for their work information. In total 96.000 € per year, what looks not economical. But compared to this, with 25 % less duration between text based and animated information [17], 5 assembly workers (salary 100.000 € each) would save 125.000 € per year and with this 29.000 € for the company a year.

All levers have three key target dimensions in common how to increase the efficiency of learning:

- Supporting the process of learning
- Increasing the motivation to learn
- Reducing complexity

First of all, the learning process itself should be encouraged by appropriate methods of support. In addition, however, the motivation has to be positively influenced, so that the worker learns of his own accord and with appropriate emphasis. Moreover, supplemental measures accelerate learning by reducing complexity and thus the learning requirements. In addition to quantitatively restricting the scope of learning, the corresponding target dimension includes measures to avoid the incorrect execution of tasks through design features of products and processes.

4. Industry 4.0 – Enhanced opportunities for learning the shop floor

Technical innovations in the framework of Industry 4.0 are mainly based on the newly developed Internet of Things and Services. Corresponding cyber-physical production systems do not only enable real-time communication, transparency and consistency across hierarchical levels and organizational boundaries, but also bring major changes on the shop floor level.

Fundamental trends and mechanisms in this context are defined as part of the High-Tech Strategy of the German Federal Government by ACATECH [18]. In addition, literature provides numerous other compilations of central features of Industry 4.0 [19; 20; 21; 22]. In the context of this paper the focus is on properties that can be used directly to influence work-based learning. Cyber-physical systems can, for instance, support production line workers, by offering new ways of gathering, processing and visualization of process data [23]. In total, six characteristics of Industry 4.0 are mentioned that address the target dimensions for promoting work-based learning. As shown in Fig. 2, this is achieved by the previously introduced technical and organizational levers. Corresponding hypotheses concerning the corresponding interactions can then be validated by empirical test series.

Real-time availability of all relevant production data is made possible by cross-linking production-related IT systems in enterprises and integrating sensors to detect status information on the shop floor. So general order data is available at all times and latest process information is gathered by analyzing completion confirmation and sensor data. At the same time, real-time data enables immediate automatic feedback for production workers.

So-called smart products also contribute to the availability of information. They may be identified and localized at any time during the production process and are characterized by the fact that they know about their current assembly status and the next production steps to come. Providing this information offers advanced options for full automation but also supports the efficient and error-free task execution by the production personnel.

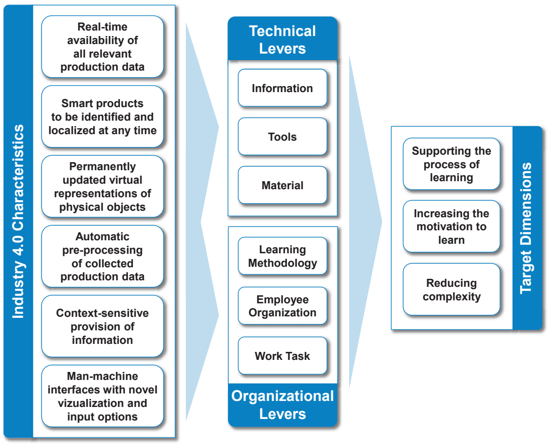

Fig. 2. Adressing work-based learning by means of Industry 4.0

At the same time, there is an exact virtual copy of each physical object within the system. These copies comprise relevant data of the original objects like products, parts and production equipment. On shop floor level, the permanently updated virtual representations can, for example, be used for visualization. In addition, this ensures that previously gathered specific properties of the physical object are taken into account for subsequent production steps without re-gathering.

By automatic pre-processing of collected production data, the large amount of existing digital data on products and processes can be filtered, combined, aggregated and abstracted to facilitate cognitive acquisition and utilization by the employee. This is particularly useful when an intuitive understanding is hindered due to the large amount of data or its complex relationships. In this case, the system can generate key figures suitable for decision making, meaning that the worker is unburdened from routine activities and focuses on his real work and learning tasks.

For automated processing of data, details of the current situation and context of fulfilling a specific task can be evaluated. This enables so-called context-sensitive provision of information. Selection and presentation of the information displayed take into account product-specific work plans as well as currently available tools and parts, but especially individual characteristics of each employee. This may include, among other details, the language used, the basic skills and the learners knowledge regarding the current task.

In addition, recent developments in terms of man-machine interfaces feature novel visualization and input options. Smart glasses, for example, offer new possibilities to implement augmented reality. Another example is using mobile devices such as tablets, which do not only make the presentation of information, but also data input more flexible. As a result, documentation is easier in many cases, enabling efficient management of information in case of failures.

In practice, each technological approach of Industry 4.0 may influence more than one lever. Usually, however, it is not desired to limit the positive effects of individual measures to specific target dimensions. The situation is different in case of possible trade-offs between dimensions, for example if reduced complexity and hence reduced scope of learning has a negative effect on motivation.

To create a holistic planning model, a complete investigation of such interactions as well as the identification of interdependencies between external influences and the addressed levers is crucial. Given the still young history of cyber-physical systems, it is important to explore the specific needs and opportunities of technology-driven solutions to support work-based learning [24]. By evaluating individual measures and assistance systems, empirical research creates the conditions for a purposeful implementation of work environments that support learning. This enables setting expenses in relation to the anticipated benefits even in early planning stages of a production system and facilitates an economically sound selection of appropriate measures.

5. Learning about learning – Empirical research at the Demonstration Factory

The Demonstration Factory is the required platform for these kind of needed empirical validation in an industrial environment. It enables solutions to be developed to the state they can directly be implemented for practical, economic usage. In Addition, different attributes a "Learning Factory" has to have will be explored and refined in this place.

The application of technical assistance systems and the growing use of digital media for work-based learning involves extensive modifications of classical educational approaches and its underlying didactics. To be able to make reliable statements about the efficacy of certain methods and measures supporting learning against the suggested background, comprehensive empirical investigations will be necessary. These investigations are not easy to implement in active production environments, because every experimental variation of working or learning processes can lead to impairments of the running production. Because of this, in these environments only data concerning the ability to support learning of the respective overall concept, for which no differentiation between single effects is possible, can be collected.

Whereas the impact of purely technical parameters can already be quantified sufficiently in laboratory studies, particularly socio-technical effects within a production system remain unconsidered so far. To fulfill the empirical need for research concerning the production of socio-technical systems without facing the described limitations, the necessary framework was created by the foundation of the Demonstration Factory of the RWTH Aachen Campus [Fig. 3]. On 1.600 m², it features small-scale production of marketable products with a high vertical range of manufacture. This includes sheet metal forming, joining of automotive body structures and a manual assembly section. The process chain as well as individual production steps represent authentic industrial requirements in terms of complexity level and quality specifications.

Within the Demonstration Factory, learning processes are addressed from different perspectives. On the one hand, a general learning about production is enabled by generating real movement data, which is then statistically analyzed with regard to current research issues. On the other hand, a thematic focus is on learning processes inside production with special emphasis on the integration of learning into the process of work. Linking these two perspectives allows substantiated learning about learning in production at the Demonstration Factory.

Fig. 3. Interior view of the Demonstration Factory

Following a new empirical methodology referred to as „Scientific Management 2.0" [25], hypotheses that were derived from theory previously are evaluated and in the case of falsification, they are modified further until a reliable statement is possible. The method will initially be used for selected use cases that are already located on the shop floor of the Demonstration Factory. Inter alia, systems for information management are included. This comprises a mobile app to capture faults of the production and its cooperative elimination as well as a comprehensive system for company-wide knowledge management.

Another focus is on support systems for manual assembly. There, different possibilities concerning work instructions are implemented and evaluated in comparison. At the moment, a connection of textual assembly instruction with the 3D-CAD model is already in use. It will be described shortly hereinafter.

A touch screen that was installed at the assembly station instead of the original printed instruction serves as a hardware interface for the worker [Fig. 4]. For reasons of visualization, the whole CAD model of every single variant to be produced is stored in the system. In every assembly step, all the components that were already assembled are illustrated on the screen. Newly added components are highlighted in a different color and assembly movements are visualized using animations. At the same time, the corresponding textual instruction is displayed and references concerning needed tools and individual parts are given. In addition, process parameters such as the tightening torque of screw connections are displayed.

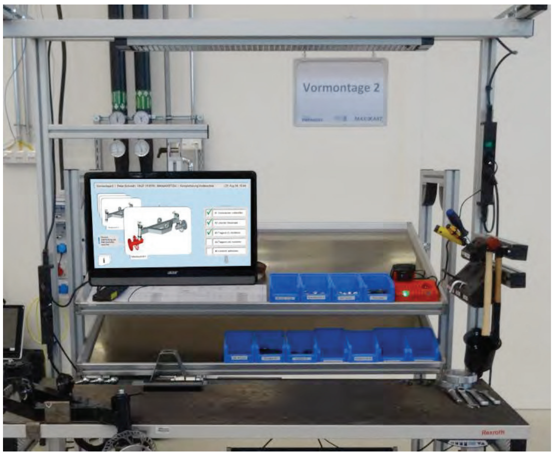

Fig. 4. Manual assembly workstation equipped with a touchscreen

In addition, direct connection to the superior ERP system and variant-specific work plans will be realized. Thus, the right assembly instruction is called automatically and the completion confirmation of each production step is executed by calling the next step. This enables accurate traceability of the entire process with minimal effort. The corresponding user interface is shown in Fig. 5.

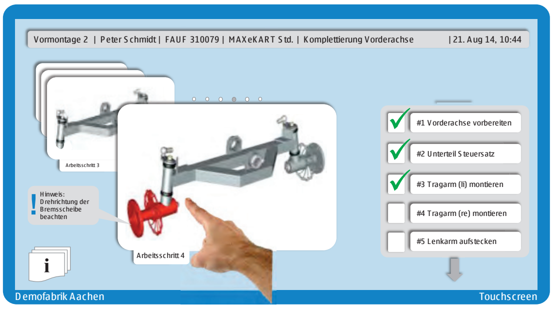

Fig. 5. Advanced user interface with optional completion confirmation

With regard to the adaptive and animated assembly instructions described, the mode of functioning is illustrated in Fig. 6 using the model presented in Chapter 4.

Based on this, the following overarching assumptions were made that will be empirically tested by observing, time recording and accompanying surveys of the respective groups of subjects over 30 working days:

- The complexity of the task and thus the learning scope for the employee declines as job-specific work instructions are displayed automatically. Thus, the detection of variants and specific steps must not be carried out by the worker.
- The process of learning becomes more efficient because the illustrative animation of individual assembly steps makes the assembly movement easier to understand, reducing the time for successful fulfillment of the task.
- There is no significant impact on the motivation to learn. Considering possible motivational effects, the positive relief from routine tasks is facing a perceived loss of autonomy.

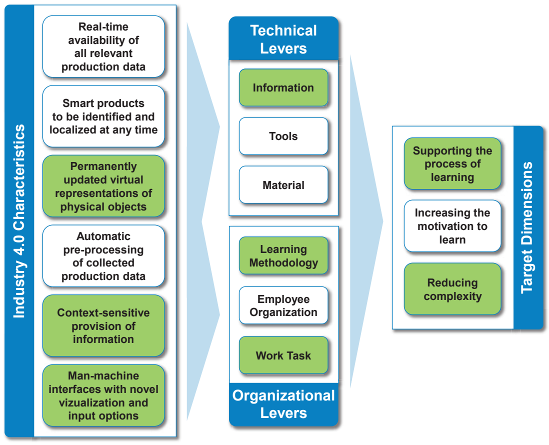

Fig. 6. Mode of functioning for supporting work-based learning by adapted assembly instructions

The complexity of the task may be evaluated based on objective criteria. The learning efficiency can be determined by classical learning curve theory based on the recorded execution times and error rates of the subjects. However, in addition, the perceived support of learning by the worker has to be included, which is facilitated by interviewing the subjects due to the subjectivity of this criterion. The same applies to the motivation to learn, which is also largely based on subjective perceptions. Taking into account these various topics, a complete picture of effects of the individual measure can be drawn. This also builds the basis for considering the economical efficiency of a corresponding implementation.

6. Conclusion and outlook

Industry 4.0 offers new technological opportunities to support work-based learning in production. Due to the novelty of such solutions, it is not yet possible to predict which measure used in which scenario has which concrete impact on human learning and thus on the learning curve of the individual employee and the entire production system.

In this paper, we introduced a model combining characteristics of Industry 4.0 with central levers aiming at the support of work-based learning. Based on scientific theory and practical experience from the shop floor, Hypotheses like “An additional employee, software and tablets can save money in a high variance assembly” are deduced to be empirically examined at the Demonstration Factory of the RWTH Aachen Campus. By bringing together a real production environment and a new structured approach to evaluation, profound conclusions about the effectiveness of certain measures are enabled. The simple example in chapter 3 shows the way how work-based learning should be calculated then. Most of the correlations between impact factors and levers have to be qualified and quantified. Based on these findings, measures supporting work-based learning can be purposefully selected in early planning stages of a work system.

Solutions currently implemented in the Demonstration Factory are permanently developed further. With regard to the practical example shown here, an automatic adaption of the level of detail for assembly instructions tailored to the needs of the individual employee is planned. Additionally, automated detection of the assembly progress by means of sensors and image capture will be tested. The individual stages of implementation will be compared to each other and to alternative solutions in order to empirically evaluate the suitability to support work-based learning.

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