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Learning Factory for Industry 4.0 to provide future skills beyond technical training

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Abstract

The paper will describe the design of a learning factory for Industry 4.0 that addresses the growing demand for future skills of production staff. Existing learning factories often focus on the technical skills whereas this learning factory also trains decision making, group work and performance monitoring skills. The paper refers to the existing categorizes of learning factories and unveils its numerous features. The conceptual design includes theoretical and practical parts, which prove to be successful in a German learning factory that was realized by the authors. Especially, for the industry 4.0 environment, the layout consists of three stages of a production system, from manual to automatized manufacturing. The practical tasks cover the introduction of smart devices, connection of information flows as well as monitoring of performance. The didactical design of the training program provides a sustainable approach by not only realizing training courses but also includes preparation with management, mid-term coaching and success monitoring after the training. The learning factory is a part of a whole research institute for intelligent manufacturing in China including consultancy and application support. One of the underlying goals of the learning factory is to enable production staff for change management, decision making and innovation.

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1. Introduction

In the last 30 years, there are three fundamental phases from CIM via lean to industry 4.0 with different training needs in each phase. The first phase, CIM – computer integrated manufacturing, emphasizes automation and information flow. The focus was on the introduction of computers on shop floor level connected with CAD and ERP systems. The second phase, the “Lean wave”, brought organizational design and segmentation of factory structures into the focus. After Womack and Jones’ analytical book “The machine that changed the world” in 1990, they discovered “lean thinking” in 1996. This changed training contents from methods and tools to additionally mind set and behaviour [13], [14].

For the third phase, industry 4.0, the focus lies on the digitization in the industry [6]. The “Plattform Industrie 4.0” for example identified a lot of potentials and challenges which are all a part of the five fields of action: horizontal integration, digital end-to-end engineering, vertical integration, new social infrastructures and cyber-physical production systems. Additionally, they pointed out the following demands as the scope for qualification [8]:

- Digital learning techniques
- Job-related qualification
- Lead and operate production systems
- Interdisciplinary product and process development
- Specific industry 4.0 competencies
- Competency evaluation

These demands and challenges show the importance of qualification and human resource development in the near future. It makes clear that industry 4.0 is more than just technology. The human resource could be probably even more important in times of industry 4.0. These demands are transferred into the training scheme of the industry 4.0 learning factory of the authors. The learning factory should cover the following three categories of skills:

- Technical skills, e.g. install and operate IT devices: RFID-tags, tablets or automatic guided vehicle (AGV)
- Transformation skills (e.g. propose and realize changes in all three stages of the production system; learn to adapt transformation principles in their home plants)
- Social skills (e.g. team work, knowledge transfer, knowledge acquiring, collaboration for synchronization of processes and delivery dates and analyzing defects)

To enable the workforce and students as future workforce with the required qualification, there are different approaches. From classical seminars, over business games, to practical case studies, where students have a jour fixe with managers from companies to solve real existing problems [7], [10].

A very promising approach to assure these required capabilities by qualification of operators and management is the learning factory concept. Over the last 10 years more and more learning factories evolved over the whole world and especially in Europe. These existing learning factories have taken many different forms. They vary in size, topics, products and other factors [12], [2], [15]. A common aim of almost all of these facilities is the hands-on qualification of the participants. This is the case even if the trainees are not employees but students. Another function of learning factories especially in the academic environment is the usage as a test area for new technologies and processes. They vary from learning factories for production process improvement (e.g. lean management methods), over learning factories for production and factory planning to those for energy and resource efficiency [1]. Nowadays more and more learning factories and labs are concentrating on topics related to industry 4.0. A lot of them are focussing on research and technology transfer instead of training and education [1]. The learning concept which the authors have developed and will describe in this paper is a mixture of both, training and demonstration. On the one hand it is dedicated to train and qualify employees from several organizations. On the other hand, it should function as a demonstrator, where participants can get in touch with new approaches and technologies.

This paper will introduce a learning factory concept which integrates the three categories of skills and tries to address the identified research demands. Therefore, the didactical design is explained first to introduce the concrete training concept afterwards. Finally, an outlook is given to show the plans for future training and research.

2. Didactical approach

The didactical approach of the learning factory for industry 4.0 was realized in an existing learning factory of the authors. It was used and proved during a great number of training. The conceptual design mainly pursues the following goals: *(i)* Activation of participants, *(ii)* Interaction with participants and *(iii)* Empowerment of the participants. The main didactical design is detailed described in [11] and consists of an alternating sequence between observation, theory and practice. There are always two trainers in minimum to create a higher dynamic regarding presentation style, moderating and discussion. The combination of theory and practical application creates a higher learning effect as any other qualification concept. Theoretical knowledge is transformed into expertise. A self-learning process becomes active which fosters a sustainable learning effect. The realistic environment stimulates all senses [5], [3]. The running learning factory, described in [12] uses a wide spread and typical production process to teach the participant's methods of process optimization according to the lean principles and philosophy. The training uses scenes to show real situations and problems from the participant's daily working lives beside the theoretical input. These scenes are played by actors (students) to give the trainees the chance to stand back and reflect, since these situations are similar to situations in their home plant. They can watch how they and their colleagues do behave during the work. Thereby they are in an observer role first and will be coached to implement improvements in later rounds at a manually operated production line. Digitization was not demanded at that time. Thus, the concept can just be seen as a general basis for the didactical design of the industry 4.0 learning factory and has to be extended now in several aspects. All adaptations of the new concept are described in chapter 3.

3. Industry 4.0 learning factory

The following part describes the industry 4.0 learning factory concept developed by the authors with its different layouts, development stages, roles and technologies. The product for all layouts is the same, a cube consisting of two halves, two pins and a filling (tablet). The material for cube halves differs between alumina and plastics of different colors.

3.1 Courses in the industry 4.0 learning factory

It is recommended to start a training program starts with a one-day management training (see figure 2). Here decision makers will get an overview about industry 4.0 technologies and examples. Additionally a rough training schedule for their staff will be created to set the starting point for a successful qualification program. The program for line workers and supervisors consists of a basic course, which should enable participants to understand the basics for an industry 4.0 implementation and a main course, which should help the participants to get familiar with industry 4.0 technologies and how they can implement parts of the approach in their own factories.

The basic course covers general principles and approaches which are required to have a good foundation for introducing smart manufacturing respectively industry 4.0 elements. This course includes short theory parts but especially longer practical parts, where the participants have the chance to experience the change to an improved production process and factory structure by their own. It is a two-day course to learn how production processes can be analyzed and optimized in a structured way. The learning environment consists of two production lines. Starting at a manual, impractical line 1, the training goal is to optimize the processes during the two-day training. The final stage will be a second line with a U-shaped layout and a conveyor under consideration of lean principles and ergonomics (see figure 1).

So, after two days the trainees should have learned:

- How to identify wastes and eliminate it,
- How to organize the working environment in standardized processes to guarantee a constant performance,
- How to measure the standardized processes,
- How to use performance dialogues as a communication media between workers and supervisors.

The following main training consists of three days and covers the advantages and usage of industry 4.0 technologies. To enhance the learning effect and show the advantages of industry 4.0 the training will start at the lean production of line 2 again. During this first part of the main training the limits of a very rigid line-layout (incl. conveyor) will be shown. Therefore, very individual orders are simulated to demonstrate the higher demand for flexibility in the industry [4]. Step by step, the participants will implement several technologies to create an intelligent, flexible und unchained manufacturing “line 3” under consideration of industry 4.0 elements and approaches. The digitization elements include the integration of a digital performance culture, which means all the information about the line’s performance is visualized on a digital screen instead of having printed paper. The product flow is transparent by using RFID-tags on each product. This makes it easy to track times and quality parameters of each product.

The introduced technologies include logistics and production equipment. AGV’s transport the products (cubes). To handle the products, they are equipped with a robot arm and a gripper. That makes it possible to realize a flexible and automated transportation system within “line 3”. In a future state this should function as a self-organized mechanism. Additionally, an automated assembly of the products is introduced to teach the participants advantages, but also challenges and limitations of automatization. To introduce the possibility of individualization, even already in the product development, a rapid prototype lab is installed. Within this lab participants should learn how to design products and how do use additive manufacturing as an option for individualization. Furthermore, a small size CNC drilling machine is used to drill holes in the cube halves. In addition to the treatment of the product, the assembly is supported by light-weight robots to teach possibilities of human-robot-cooperation (e.g. at packaging or optical inspection). After the first two days of the main training the participants should have a feeling which technologies could fit to their own factories requirements and how an implementation could look like.

The third day is used to discuss and plan the implementation of first elements of industry 4.0 by planning pilot projects at the participants’ factories and workplaces.

So, the general goals of the main training are:

- to train the participants how to implement certain cyber physical technologies,
- to show examples, approaches and advantages of industry 4.0 to the trainees,
- to coach methods to plan and transform their own work environment and processes.

3.2 Three stages approach

To create an effect of success to the participants, three different optimized situations are used. This means the concept follows an approach of three stages realized by three production lines, that all produce the same product, a cube. The first line is completely manual. It uses only tables, human power and simple tools. The second line can be described as a lean production line with semi-automated working stations and professional working benches. Line 3 shows an industry 4.0 production realized by implementing new technologies and approaches to create an intelligent manufacturing. The layout resembles a workshop production with different production islands. During all three stages the same didactical approach is used. Starting with an observation of a non-optimal situation, getting a very short theoretical input and realize an improved status in the end. Additionally the measurement of success is a part of all stages. Figure 2 shows the layout of line 1, line 2 and line 3 in comparison to give the reader an impression of the step by step improvement process.

3.3 Sustainability of training

Experience shows, that even if a training does successfully transfer new knowledge to the participants, it is not guaranteed that it will be applied to its full extent. The coaching approach of the authors learning factory for industry 4.0 stems from this experience. The new coaching process (see figure 2) foresees visits of trainers at the workplaces of the participants back in their home plants. The particular tasks are to find out if the managers support the change processes in their company, if the participants identify areas to be improved and started a project and if the participants are familiar with all the methods they need or if a retraining is required. This kind of success monitoring and coaching

support after the training is an inherent part of the training concept. It is of high importance to realize a real change within the participant's organizations. Since in most of the existing learning factories and training approaches trainees will leave the course without any specific task related to the learned skills it is a huge challenge to measure the success of a training and the real effect on business success. This is why the authors lie a special focus on the sustainability of trainings. The systematic coaching (incl. pilot projects) is an approach to emphasis this topic. When it comes to the success monitoring according to Kirkpatrick, there are four levels of learning success evaluation: Reaction, which means the feelings of the trainees in and after the training; Learning, which reflects the actual improvement of the participant's knowledge; Behavior, which evaluates if the trainees actually change something to the better within their real working life; Results, which try to summarize the effect of the training on business results. So these four levels can be summarizes in the following questions [9]:

- Did the participants of the learning factory course understand and learn the lessons and methods?
- Could the participants apply their new knowledge in their home company?
- Do the results reflect the successful learning?

Trainers rely heavily on the group work impressions and discussions to monitor *question 1*. They have to ask each member of the small groups to show their knowledge. Concerning monitoring *question 2*, the effect at the company, an important pre-step is the definition of measurable goals for the following pilot projects with the managers of the company. This could work by choosing three sub aspects related to the learnings (e.g. shorten the throughput time, increase flexibility or teach other people how to map a process). If the goals are specified in this way, then it is possible to monitor the project success caused by the learning factory. Figure 2 shows the overall approach of the concept to foster the sustainability of the training. This includes a guidance for the participants which is foreseen before and after the training as well.

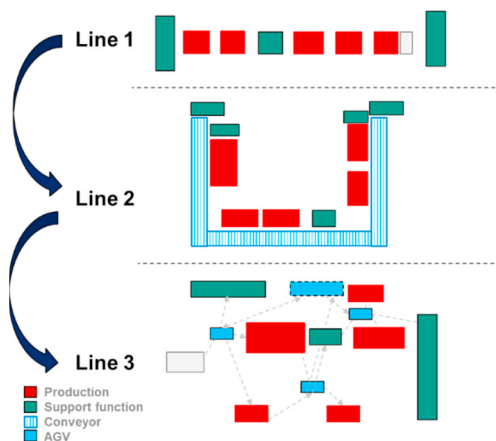


Fig. 1. Layout transformation.

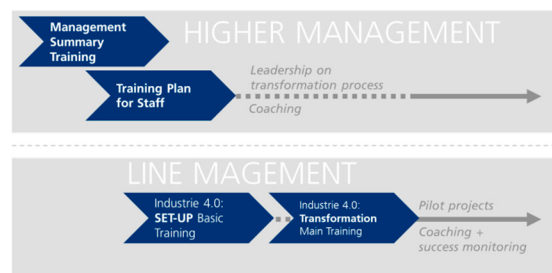


Fig. 2. Coaching and guidance during the transformation.

It starts with a preparative management summary training which sets the basis for a successful qualification program. One result of this one-day training is a training program for the staff of the respective management. This first phase includes a preparation and coaching on leading the transformation process. This should assure the top managements support for the whole project of the organizations right from the beginning. The approach shows that not just a training service is offered but also a guidance and stronger cooperation during the whole transformation to industry 4.0. After the training schedule is fixed, the basic and main training will start to qualify the line management to realize the transformation within their own working places and factories. After the training the participants will receive additional help to carry out the transformation. Therefore, a coaching and guidance approach is used with six

meetings in six months for the higher management and an on-site support for the line management during pilot projects. The support package of coaching, training and guidance will end after first successful implementations are realized at the factories of the participating organizations.

4. Summary and outlook

The paper describes a newly developed concept of a modular learning factory for industry 4.0, which is part of a research center with the components demo center, application center and training center. The learning factory is based on the principles of action learning and social learning and addresses learning for industry 4.0 by practical tasks of implementing technical artefacts as RFID, additive manufacturing, robots and digital performance boards. Participants should not just get to know technologies, but they should learn how to choose the right technologies and how to implement industry 4.0 approaches at their own work spaces and factories. To support this process, the advantages and possibilities of industry 4.0 are addressed in several ways. Beside the learning factory a demonstration center is to be built, where some booths with physical workplaces and cyber physical system as well as equipment from successful industrial application projects can be shown. Since the concept of the authors is still in the implementation phase, there is probably still a need for adaption at several points to improve it after the first pilot training. Especially the planned monitoring of learning success by defining measurable goals for projects after the training is of high interest for the authors. It will be seen if the described approach of coaching and pilot projects will work. It remains to be seen which special topics outside the two base courses at the production lines are taken on by trainees and where the focus of training courses will lie in the future. As one of the main goals is to qualify trainees from the industry this is also very depending on the industrial needs of the future. It is planned to introduce special topics for particular industry 4.0 technologies as 3D-printing or smart logistics. Additionally, the extension of the learning factory by another facility within the same building is planned and envisaged to be realized after the successful completion of the described learning factory.

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