Abstract

Future production faces challenges such as shorter time-to-market, high number of product variants and limited resources. To meet these challenges qualified employees are required. With the approach of learning factories methodological, social and personal competencies of employees are increased. For the education of methods, technologies and tools for the product creation a product lifecycle (PLC) approach is chosen which includes research fields such as Innovation Management, Engineering Methodologies, Production Management and Virtual Engineering to create a holistic practical learning framework based on a constructivism learning approach. The learning factory concept centers Systems Engineering (SE) as a structural element for projects by SE specific processes and role models.

1. Introduction

Increasing global competition forces companies to constantly reduce the time-to-market of their products. This involves reducing not only the product development time but also the production time. However the increasing complexity of products, high numbers of product variants, limited resources and demographic change [2] are becoming the new challenges for an effective production. For managing these challenges, well trained and educated employees have to possess competencies of different disciplines.

The Product Creation Process (PCP) includes various phases to develop a complex product. Concepts like Industry 4.0 confirm the future product development based on several disciplines such as mechanics, electronics and informatics. Research fields such as Innovation Management, Engineering Methodologies and Management, Integrated Production Management and Virtual Engineering deliver information, methods and techniques for the PCP. Mechatronic and cyber-physical products suffer from an increasing complexity. Systems Engineering (SE) is an methodology to coordinate and connect different disciplines for the development of complex projects or products [7,18].

Usage of conceptional approaches like SE challenges enterprises in terms of coordination, communication and the needs for a common understanding within interdisciplinary teams. For the implementation of approaches like SE employees must possess fundamental know-how of processes and characteristics of SE. One possibility to impart knowledge are practices of studies to educate systems engineers. This paper deals with an educational approach of a learning factory focusing basically on the PCP, covering all phases from product ideas to manufactured products. Another important aspect is the integration of research fields. The aim of the educational concept is the increase of competence-oriented learning outcomes and the implementation of student centric methods for active application of theoretical knowledge. The attempt of the learning factory includes research fields being necessary for the PCP, but also takes the focus on the design methodology SE for a practical usage of processes and methods of SE which are rarely implemented in companies.

2. State of the art

The section shows the morphological approach of teaching methods by Steffen [13], the modified morphology for learning
factories by Tisch [15], challenges for the development of competency which can be solved by educational methodologies such as learning factories and two examples for learning factories, away from resource efficiency and “Lean Production”.

2.1 Learning Factories

The didactical approach of learning factories has various definitions. The expression “learning factory” is composed of the words “learning” and “factory” which include different aspects. The first element involves an educational approach of learning and teaching. The second element “factory” describes the industrial environment which is necessary for the industry-related education [1, 16].

A classification of courses is possible with the generic morphology of teaching methods by Steffen [13]. A learning factory concept can be categorized by a modified variant of the teaching morphology developed by Tisch et al. [15].

Tisch et al. developed an approach for an action-oriented, competency-oriented learning factory. With the help of this approach, called Learning Factory Curriculum Guide, a learning factory design should be provided for the improvement of target groups’ competencies. The first part of the procedure, entitled “first didactic transformation”, focuses the required competency development by an analysis of target groups. Additionally for the competency development the second didactic transformation assigns suitable teaching methods by the morphology of teaching methods [14].

Additionally Adolph et al. describe challenges for the development of competency such as globalization, penetration of new technologies, more dynamic product lifecycles, limited resources, etc. and provide methods to handle challenges [2].

A various number of learning factories were established worldwide during the past years. The configuration differs by main topics for education like energy and resource efficiency or lean management [4, 8, 9, 10, 12]. The following paragraphs (2.2, 2.3) provide two examples of topic specific learning factories.

2.2 LPS Learning Factory Bochum

The LPS Learning Factory in Bochum deals with three different topics: process optimization, resource efficiency and management and organization. These topics include methods of “Lean Production” and material and energy reduction. Management and organization includes investigations of cobdetermination, work councils and integration of handicapped or older employees in the production process.

Bender et al. (Chair for Product Development, Bochum) describe an additional methodology for an enlargement of the learning factory concept, called Learning Factory 2.0 [3]. The holistic procedure gives the possibility to investigate and impart communication and cooperation between product development and production. The lecture for students is conceived as a business game, including virtual models and simulations. The FMEA method acts as a communication tool between production and product development groups to improve processes [3, 8, 17].

2.3 Demonstration Factory Aachen

Schuh et al. developed a holistic approach at the RWTH Aachen. They focus on future production in context of Industry 4.0 and point out the requirements for a learning factory. A specific focus is defined for technological and process changes by Industry 4.0. An emphasis on work-based learning implies influencing factors (product, process, personal), as well as technical (information, tools, material) and organizational (learning methodology, employee organization, work task) levers. By an analysis of trends, Industry 4.0 characteristics were identified and combined with the work-based learning approach. For the validation of use cases based on Industry 4.0 such as human-machine interfaces, context-sensitive provision of information and virtualization of physical objects, the already existing Demonstration Factory in Aachen is used. It includes machines for sheet metal forming and joining of automotive body structures as well as stations for manual assembly. [12]

2.4 Research fields in PCP

The research field “Strategic Planning and Innovation Management” deals with the analysis and prediction of social and economic environment being realized with scenario technique. Another important aspect is the development of suitable business models with Business Model Canvas, especially in context of Industry 4.0. The implementation of an innovation culture in enterprises is created by innovation workshops with creativity techniques.

SE provides processes and methods which accompany all phases of the PCP. A specific aim of SE is the linkage of different disciplines such as mechanics, electronics and informatics. Approaches of design methodology such as VDI 2206 or agile design methodology are possibilities to increase efficiency of design and production processes. Nowadays innovation can often only be reached at the expense of high complexity of the technical system. For example mechatronic and cyber-physical systems require interdisciplinary collaboration. Therefore methodologies dealing with these complexities gain importance. SE is a promising approach to deal with complexity, especially for communication and collaboration of various disciplines.

“Production Management and Automation Technology” deals with the early implementation of production planning and the development of cyber-physical decentralcontrolled production systems. Especially the communication of centrally controlled systems is a fundamental research topic. Another important aspect is the coexistence of human beings and machines in production environments.

The research field “Virtual Engineering” includes the support with digital tools, innovative technologies and a holistic IT-infrastructure for the PCP. One aspect is the integration of development software to increase the penetration of virtual and decrease of physical prototypes. Another aspect
is the implementation of innovative technologies such as Virtual/Augmented Reality in different phases of the PCP.

3. Educational approach for Product Creation Process

This section includes the PCP Learning Factory and the role of SE within. Additionally the linkage between research and education is described and a modified morphology for the product lifecycle (PLC) learning factory developed.

3.1 Holistic approach

The educational approach of a learning factory focusing on strategic planning, product development and production have to include a PLC as a basis including all necessary phases for the whole lifecycle of a product. The holistic approach of a SE focused learning factory with influences of different research fields is illustrated in figure 1. The modified PLC consists of phases from the market analysis to the recycling of the product. By the holistic consideration of all phases all information of the product are available for development, production, service and maintenance.

Fig. 1. PCP learning factory concept

The procedure centre is formed by a) the design methodology SE which contains a various number of processes to structure the PCP and b) a role and task model of a systems engineer. SE includes interdisciplinary development and production in the learning factory approach. All elements of SE support for PCP are more precisely explained in 3.2.

3.2 Role of Systems Engineering and Systems Engineers

SE deals with the complexity of technical systems. To support SE and to resolve the complexity, four groups of processes are identified by ISO/IEC/IEEE 15288 (INCOSE): technical processes, technical management processes, agreement processes and organizational project-enabling processes. To develop a successful system, systems engineers should not only deliver an effective and efficient system development but also ensure that all involved stakeholder requirements are met. Various role models of systems engineers exist; all of them consist of tasks to deliver these requirements. Sheard [11] summarized generalized tasks of systems engineers into twelve role models. These role models are divided into “life cycle-roles” and “program management-roles”. Life cycle-roles conclude specific engineering support tasks. Program management-roles primarily deal with general support tasks such as collaboration with customers [11].

SE incudes several processes supporting PCP (as illustrated in figure 1). For example in the stage “product concept” the architecture definition process is very important to generate system architecture alternatives and select one or more alternative(s) to meet the requirements considering stakeholder concerns [18]. The System Designer (SD) role is established for this process. An engineer in this role creates the high-level system architecture and designs and selects major components [11]. System analyses like system weight, power and throughput determined by the System Analyst (SA) role are necessary to support SD.

In stages after production the following processes become key tasks of SE: Transition process, which can provide services specified by stakeholder requirements in the operational environment; Operation process, which is to use the system to deliver its services; and maintenance process to provide a service. That means there are still a great deal of problems waiting for systems engineers to solve. For example, systems engineers serve “on call” to answer questions and resolve anomalies with the role model of logistics and operations (LO).

3.3 Linkage between research and education

The inclusion of research field relevant methods and tools in learning factory are based on methods of the constructivist approach Cognitive Apprenticeship including six steps [6]: modeling, coaching, scaffolding, articulation, reflection and exploration. The first step is the practical visualization of methods or tools by demonstrating them in modeling. The following step coaching focuses the observation of lecturer while learners use methods and tools. Support by the lecturer is given in scaffolding. The articulation step has the aim to transfer the learned knowledge by usage for another problem-based task. In reflection learners analyse their knowledge and usage of methods by comparison with other learners and the lecturer. Finally the learners go beyond the learning of methods and generating of knowledge by discovering interest and creating own aims. [6] In context of the PCP Learning Factory the Cognitive Apprenticeship model is presented as an iterative process which has to be performed several times for different methods and tools of research fields.

The implementation of Cognitive Apprenticeship is necessary by a number of points such as high complexity of tasks and problem-based tasks, high level of cognitive and metacognitive processes and learning in teams being focused by this approach [6]. For the learning of methods and tools of research fields the steps from modelling to reflection must be passed through. With the help of this approach content of several research fields will be imparted.
3.4 Morphology of learning factory

Based on the modified morphology of Tisch et al. [15] a specific framework for the PCP Learning Factory focusing the infrastructure of the Chair for Product Creation in Paderborn is developed (figure 2). The management and input for the concept are delivered by professors and researchers of mechanics, electronics and informatics as well as technical specialist of the different disciplines. The main purpose of the concept is education and research. Students practise the theoretically learned methods, tools and technologies to increase their competencies. Another possibility is the usage of infrastructure to write study theses. In the area of research, the concept provides the possibility to validate approaches and technical systems. In this case, the concept is used as a research enabler for validation. The learning factory concept itself is a research object to investigate user experience in context to methods, software and technology. For investigations of user experience, the implementation of usability engineering tools and infrastructure is necessary. For the investigations of self-organized and self-configured production systems, examples for mass customization are implemented. Looking at the degree of automation the learning factory must be separated in product development and production. An almost fully automated production is an aim of future factories and shifts the task of human beings from activities on the assembly line to controlling and maintenance activities. Today the human-machine interaction is a topic which is investigated by assembly stations for cooperation of robots and humans. For the product creation it is important to generate a working IT-infrastructure with suitable software and hardware. A fully automated product creation is not realistic because of factors such as creativity and innovation. In terms of IT-integration it is necessary to integrate development software such as Computer Aided Design (CAD), Computer Aided Engineering (CAE) and Computer Aided Manufacturing (CAM). For this, typical software of industrial practice are applied to illustrate an actual and future company. Innovative technologies like Virtual and Augmented Reality provide several applications in product development such as more intuitive visualization of a product by Virtual Reality or in production such as natural user interfaces and operation panels to communicate with production systems by Augmented Reality.

In the production of the learning factory conventional and innovative manufacturing processes are integrated. Processes such as additive manufacturing (primary shaping process) are disruptive technologies which must be investigated to realize the full potential. Conventional manufacturing processes such as lathing and milling (cutting processes) are standards and describe a representative status in several sectors of engineering industries.

Learning competency is one of the main function of a learning factory. These competencies are divided in four categories: technological and methodological, social and communication, personal and activity and implementation oriented competencies [5]. Aim of the PCP learning factory is the improvement of all competencies to educate engineers with problem solving skills. Especially the role of a Systems Engineer needs a wide range of competencies to be a generalist in projects. The technological and methodological competencies increase through the practical application of methods, technologies and tools. The work in project groups over the period of a semester promotes the social and communication competencies and shapes the personal profile of participants. Additionally working in project groups and liberties for choosing of hierarchies increase the personal competencies of every participant by self-determination and self-organization. The improvement of activity and implementation oriented competencies depends on intrinsic motivation of participants and the focus of the project goal. The course trainer has different functions for the PCP
The presentation of task and method relevant input to refresh the knowledge of methods and impart information of the specific project is one of the functions. In a project with a duration of a semester, problems and challenges will occur. Based on these situations, the motivation of the course trainer is a function. Professional experiences are important for the assessment of activities such as the product development or production planning. Students who participate miss partially the required experience which can be provided by the course trainer in critical situations.

The modified morphology includes also infrastructure information of a possible course such as type of the course, number of participants, duration of the course and the capacity utilization in a year. The course type of the PCP Learning Factory is a project work with a duration of a complete semester which is necessary to create and manufacture a product. By the high complexity of a learning factory based course, the number of participants must be limited to maximal 15. For the implementation of the course, the participants have to be categorized in different task groups. The centralized task group is the SE group with different function such as the implementation of superordinate processes and communication interface of different disciplines. The other participants form discipline-specific task groups. These illustrates the organizational structure of industrial companies. The other task groups deal with the interdisciplinary development of product and production system. For this they use methods, tools and technologies of the PCP Learning Factory. The recruiting of different disciplines is possible by the scientific orientation of the Heinz Nixdorf Institute in Paderborn which integrates chairs of mechanical engineering, electrical engineering, information technology and economics. The cooperation of these discipline-specific chairs make the implementation of an interdisciplinary course such as the PCP Learning Factory possible. Through the duration of one semester it is optimal to offer the course one time a year because of the complexity.

4. Use case: mechatronic product

The developed learning factory approach provides many possibilities to improve different categories of competencies. To illustrate a possible implementation a use case of the PCP phase Product Development is analyzed in context of the development and production of a mechatronic product. In this case it is a remote-controlled model car. Section 4.1 describes the integration of Systems Engineering and research fields. The implementation of the Cognitive Apprenticeship approach for the use case is explained in 4.2.

4.1 Integration of Systems Engineering and research fields

The starting situation for the use case includes results of the first three phases. These results are an investigation of the market situation with methods such as Porter’s Five Forces or Stakeholder analysis in Market Analysis and the usage of IT-supported Scenario Technique in Scenario Design which contains a various number of market development scenarios of a remote-controlled model car. Product Concept delivers a developed business model.

For the development of the product, input of Virtual Engineering, Engineering Methodology and Management and SE is required. Methods and tools of the research fields are illustrated in figure 3. Identifying requirements is one of the first steps. With the help of a requirements list, the product functions can be delimited and determined. For the example of the remote-controlled model car there are several important requirements which depend on the imagination of customers and other stakeholders. The product architecture has to be structured at the beginning of development for the planning of the production systems. A large portfolio of product variants can lead to changes of the production processes and systems. The remote-controlled model car can be differ by design of the chassis to create a high number of variants.

Fig. 3. Integration of research fields in PCP learning factory

The development of a product is handled with design tools and software (CAD, polygon-based modeling) being important for the geometry of the product. For the remote-controlled model car the geometries of different parts must be generated with a CAD software. To investigate properties of a product simulations are required such as Finite Element Method (FEM) or Computational Fluid Dynamics (CFD). With the help of these software, physical prototypes can be reduced and substituted by virtual prototypes. Elements of SE influence the chosen use case being illustrated in figure 4.

Fig. 4. Integration of SE in PCP learning factory

Referring to the selective use case Product Development from the PCP of the remote-controlled model car, SE’s first concern should be coordinating yet undefined, respectively unknown
elements with risk management. Risk management is a core SE process to eliminate risk potentials or decrease their consequences. There are also many other important processes like requirements analysis, functional analysis and design processes to support the Product Development stage for these elements. The correct assignment of suitable role models to these SE processes is difficult. Despite a clear division of different role models, significant interactions among these roles still occur. Taking focus on “risk management process”, risk analysis is a part of the system analyst role, risk identification is a part of the glue role, and the risks management has been included in the technical manager role [11]. After finishing the concept phase, the engineering design will be started. All elements of the remote-controlled model car should be designed simultaneously. The design definition process is most relevant to provide sufficient detailed data and information about the system and its elements to enable the system design. As part of the technical manager role, systems engineers have to launch the reviews and track action items for example.

4.2 Realization of the educational concept

Based on the Cognitive Apprenticeship model, methods and tools are taught for the participants of PCP Learning Factory. First of all, tools of requirements management are important for the phase Product Development. The implementation of requirements list is demonstrated on a simple product (such as a pedelec) by the course trainer in modeling. The task of participants is the observation of the trainer. Next step is the implementation by participants of a simple product being supported by the course trainer in steps coaching and scaffolding. After this lesson participants have to apply the learned knowledge for the aim of PCP Learning Factory. In this case, it is the task to create a requirements list for the remote-controlled model car in step articulation. Finally participants present the results of the requirements list. For the learning of IT tools such as CAD software being important for Product Development, the learning process is similar. In modeling the course trainer shows a live demo of a simple product construction. After that, participants design with the CAD software a simple product and are supported by the course trainer in coaching and scaffolding. Finally the CAD software is used for the product development of the remote-controlled model car and finally presented. This process has to be repeated for learning of chosen tools and methods.

5. Conclusion and outlook

PCP Learning Factory concept is based on a PLC approach with regard to all phases of the PCP. Additionally the concept provides the interaction between education and research fields in the learning factory by a constructivism based Cognitive Apprenticeship model. A central topic is SE which structures complex projects with processes and a specific role model. SE serves in the learning factory as a guidance for engineering complex systems. For an implementation of the concept in educational environments a structure based on a modified morphology is generated. The next steps for the integration in educational university environments is the construction of a physical learning factory environment which fulfills the requirements of the learning factory morphology. For the implementation of the concept discipline specific methods, technologies and tools must be selected by mechanics, electronics and informatics to increase the interdisciplinary character of the project course.

References