INTERNATIONAL DESIGN CONFERENCE - DESIGN 2016
Dubrovnik - Croatia, May 16 - 19, 2016.

PROTOTYPE OF A NEW LEARNING FACTORY - AN EDUCATIONAL APPROACH TO INTEGRATE PRODUCTION AND PRODUCT DEVELOPMENT

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Keywords: design education, concurrent engineering (CE), interdisciplinary collaboration, learning

1. Introduction

Since nearly 25 years research proposes the strategy of simultaneous engineering in product development [Eversheim et al. 1995]. The idea is to develop high-quality products at lower costs and reduced time-to-market to be competitive in today's globalized markets due to temporary overlapped and integrated work processes instead of isolated subsequent workflows [Bullinger and Warschat 2012]. By integrating lifecycle spanning disciplines as production engineering or industrial services already in the early phases of the development, avoidable and cost-intensive iterations can be prevented.
However, the application of simultaneous engineering in a company requires appropriate organizational, technological and personal conditions. Whereas the organizational structure and technological base (e.g. IT-support systems) are already at a sophisticated standard, human factors like attitude, motivation, competences or creativity are increasingly move to the fore [Zink and Eigner 2013]. Human factors influence the performance and the motivation of human beings within a work system whereas their behaviour and interaction can be differentiated in a micro-, meso- and macro-level. On the micro-level the research focuses on the individual's relationship with the working system due to organizational, technological, personal and economic boundary conditions. The meso-level describes a person's consciousness in a group as the cooperation and information processes within interdisciplinary project teams, definition of interfaces among group members or motivation and ability to engage within constructive dialogue with certain disciplines. Aspects like cooperation amongst business processes in terms of the identification and consideration of interests and requirements of diverse departments, strategic orientation, impact of the organizational culture and self-centred behaviour of departments are examined at the macro-level [Zink and Eigner 2013], [Ernst 2014]. Different competences on each level affect the processes of product development and are required for its success. Therefore Heyse and Erpenbeck differentiate necessary competences in four categories. According to them a systematic development of personal competences (openness to change, authenticity, holistic thinking), activity and operation competences (decision making capability, goal oriented behaviour, repartee), social and communicative competences (conflict solving ability, problem solving ability, communication skills, integration capability) as well as professional and methodological competences (project management, analytical skills, proceed systematically) has to be aspired [Heyse and Erpenbeck 2009]. This propose is acknowledged by the statement of employers that in addition to expertise these competences are main factors of employability which is concluded on a study from the Deutsche Industrie- und Handelskammer (DIHK). According to this study a significant part of university graduates still have a lack of general competences [Tekkaya et al. 2013]. In order to prepare students for the work

requirements of companies, where product development is a key process within the value chain, higher mechanical engineering education needs to concentrate inter alia on developing these competences in the context of simultaneous engineering.

This paper focuses on the integration of product development and production engineering. Specific work processes that concern both disciplines can be supported by methods (e.g. hybrid FMEA (Failure Mode and Effects Analysis), MTM (Methods-Time Measurement), Design for manufacturing, etc.), but they are only applied in practice if their necessity is recognized. So it is important to sensitize students to the necessity and advantages of an integrated view first. Learning factories, which have been established in the discipline of production engineering to identify and simulate problems within manufacturing processes [Abele et al. 2010], also seem to be an interesting approach to reversely retrace the advantages of considering the manufacturing processes for the product design. On that account the deduced research questions for this paper are: Do learning factory approaches in the context of product development and production already exist? What should such learning factories look like to depict the aspects of simultaneous engineering for both disciplines?

Following the Design Research Methodology by Blessing and Chakrabarti [2009] the 'descriptive study I' analyzes didactical approaches in universities and in specific existing learning factories. Moreover, the research literature was screened for considerable aspects of efficient learning resulting in a description of the conceptional basis for the proposed learning factory concept. In the 'prescriptive study' a learning factory prototype was developed, which was initially tested and evaluated in the 'descriptive study II'.

2. Conceptual basis of the new curriculum

A quite obvious didactical approach to close the described gap between the industrial demands and the education at universities is to make simultaneous engineering the subject of lectures. While in some universities it is only the topic of a single product development lecture some chairs generated a whole course covering this topic (e.g. "Integrated Product Development" at the Karlsruhe Institute of Technology or "Concurrent Engineering and Design" at the University of Ontario). But content-oriented teaching alone as in conventional lectures is often assessed as not satisfactory for students to consolidate the theoretically taught knowledge.

2.1 Shift from teaching to learning

According to the propagated "shift from teaching to learning", which is associated with a shift to competence-oriented learning outcomes, rather student centred approaches with active learning methods in the context of product development processes are required. This means that acting consciously and independently in an authentic context causes lasting learning results [Tekkaya et al. 2013]. Different didactical concepts in the context of simultaneous engineering have been developed implementing this idea by using the project-based learning approach. Teams of students, usually from different disciplines, are confronted with a realistic task which has to be solved by applying previously learned methods [Tekkaya et al. 2013]. Examples for this kind of curriculum are the projects globalDrive at the TU München, the collaborative Advanced Design Project at the TU Darmstadt, or the Team X at the California Institute of Technology. In these long-time projects students in multidisciplinary teams have to collaborate to develop the idea and the prototype of a real product. Implementing simultaneous engineering methods sharpens their soft skills and general competences. But there might be a weakness in this kind of concept that the students not necessarily have to work in the intended way to finally create the product design and the prototype. Another approach is the problem-based learning which focuses on the learning process instead of the developed product. There students are confronted with problems and solve them by developing the required knowledge in a collaborative way with iterative reflection and optimization cycles [Bach et al. 2011]. In context of simultaneous engineering an advantage of this approach is the enhanced students' focus on actual problems which might only be handled implicitly and provisionally in interdisciplinary projects. The same principle of learning to solve problems in concrete situations is addressed in learning factories though it is primary focused on the operation of machines. But with the key objective of action-orientation and the transfer of knowledge in a situational context it complies with the requirements of the described shift to learning [Tekkaya et al. 2013]. So learning factories can offer considerable potential for the education in context of simultaneous engineering.

2.2 Learning factories

Numerous universities already designed and implemented learning factories for the education of engineering students. A 'learning factory' is defined as a location with a realistic factory environment and direct access to production processes and conditions which enables problem- and action-oriented learning [Abele et al. 2010]. This exercise offers students the possibility to practice the previously, but only theoretically learned contents in a real production area. This combination increases the learning effect and the rate of recall in comparison to conventional teaching concepts [Dehnbostel 2008]. The production area provides real-life manufacturing machines as well as assembly workstations which represents the whole process chain of a gate-to-gate production process for a real product [Kreimeier et al. 2014].

The European Initiative on Learning Factories mapped and analysed current learning factories and generated a typology of the existing approaches to support a systematic design of learning factories [Tisch et al. 2013]. Regarding to Tisch et al. all analysed concepts have in common that the learning targets are oriented on developing the capability to handle real situations and even complex problems in the field of manufacturing engineering. The didactic concept furthermore has to consider the participation of heterogeneous target groups. At the Ruhr-University Bochum a learning factory exists at the Chair of Production Systems (LPS) which is already covering main aspects of the typical production process and also current research topics. In addition, it is not only used for education and research but also for make-to-order production. Before the LPS learning factory was implemented, the machines have been used for manufacturing of real customer orders. So this production area with its heterogeneous machinery of different ages is a particularly realistic image of a manufacturing environment [Kreimeier et al. 2014].

In summary, nearly all existing learning factories address the optimization of production processes (e.g. manufacturing or assembly training) whereas the upstream product development processes receive almost no consideration yet [Tisch et al. 2013]. Regarding the industrial demand for graduated students with competences required for the implementation of simultaneous engineering a new learning factory is developed at the Ruhr-University Bochum that addresses the interdisciplinary work of product developers and production engineers. Considering that the next chapter describes the investigation of how the learning factory has to be arranged.

2.3 Additional learning aspects for conception of the new learning factory

Organizational learning can be realized by following the four related processes intuiting, interpreting, integrating and institutionalizing described in the 4 I framework [Crossan et al. 1999]. Crossan et al. define these four processes as follows:

- Intuiting is a process of preconscious recognition of pattern and possibilities inherent in a person depending on his/her experience. So intuition is a unique phenomenon that affects the individual's actions.
- Interpreting means explaining an insight or an idea with words or actions to one's self or to other persons (e.g. other group members). It is a process of refining and developing intuitive insights, but this process becomes more robust in conversation with others.
- Integrating describes the development of a shared understanding among individuals and taking coordinated actions by members of a group.
- Institutionalizing means the process of defining tasks, specifying actions and implementing organizational mechanisms to ensure that routinized actions occur. The learned aspects by individuals and groups are embedded into the organizational system, structures, procedures and strategy.

These processes occur over the three relevant learning levels: intuiting and interpreting occur at the individual (micro) level, interpreting and integrating occur at the group (meso) level and integrating and institutionalizing occur at the organization (macro) level [Crossan et al. 1999].

In the approach presented, the 4 I framework is combined with the idea of communities of practice (CoP) due to a better understanding of the intended learning goals by interacting in a social and physical environment. It is an integrated learning approach where the participants engage in joint discussions and activities that enable them to share information and thereby learn from each other. The students learn how to participate as an individual in achieving a community goal by developing a common language, communication style or methods and tools [Wenger and Snyder 1998]. This combination is used by Süße and Wilkens to create a learning scenario addressing the integration of the product and service domain [Süße and Wilkens 2014]. The same approach is also used for the integration of product development and production in the presented learning factory.
Another important aspect which has significant influence on the conception is the use of negative experiences (dilemmas). These are assumed to provoke learning processes which lead to a sustainable competence acquisition. After individuals have been confronted with dilemmas, they reflect these negative irritations and transform them to cognitive and emotional patterns which remain in memory for a long time [Schüßler 2008].

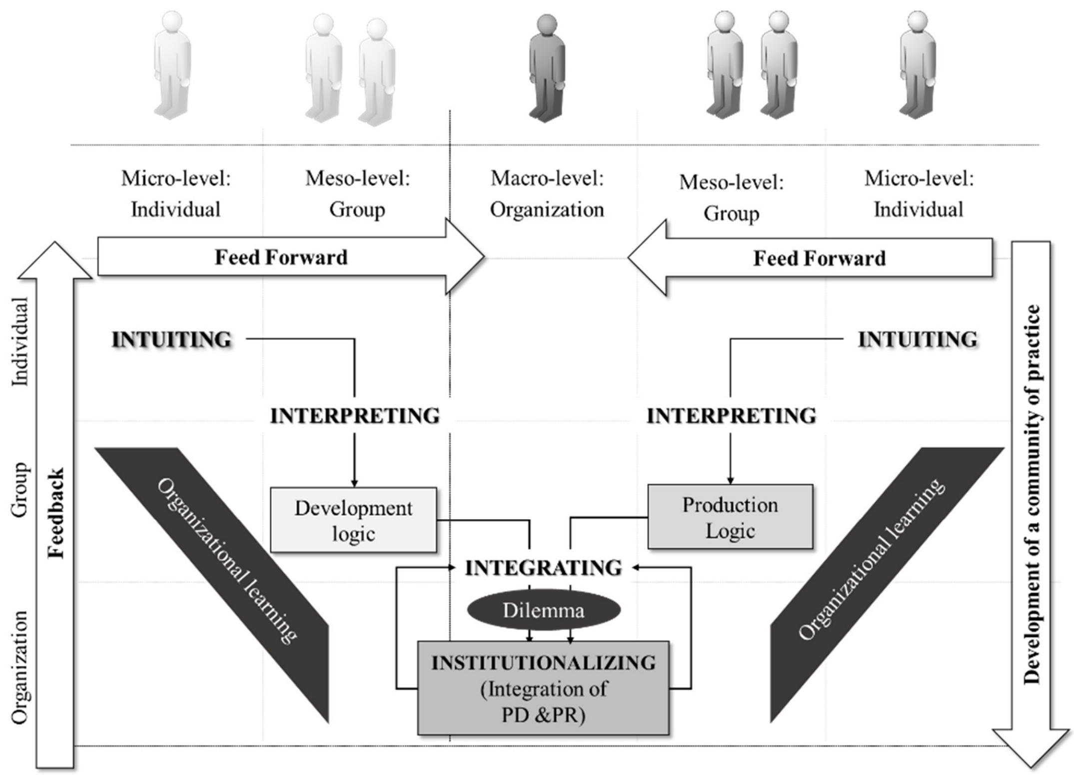

Figure 1. Conceptual framework for the new learning factory

Figure 1 summarizes the resulting concept of the new learning factory which considers the 4 I framework as basis for its procedure as well as the ideas of communities of practice and negative experiences to increase learning effects.

3. Prototype of the new learning factory: cooperation between product development and production

A first prototype of the new learning factory was tested in February 2015 with a group of 20 students to verify the designed concept and to use the results for further improvement. This 4-hours-exercise was offered to Bachelor students of the subjects 'mechanical engineering' (ME) and 'sales engineering & product management' (SEPM) attending either the course "fundamentals of product development" held by the chair of product development (LPE) or the course "networked production systems" held by the chair of production systems (LPS).

The idea is to create a role play where the students come into a conflict situation which is representative for a real-life producing company. In the course of this role play (Figure 2) they experience issues (dilemmas) in the inter-functional contact of product development and production which often arises when these departments work independent from each other. Following the idea of communities of practice the participants are guided through joint activities to develop an awareness for the importance of interdisciplinary cooperation. By completing tasks over three phases, the students are lead through the 4 I processes intuiting, interpreting, integrating and institutionalizing whereby the last two processes are realized by applying an exemplary method to overcome the case-specific barriers.

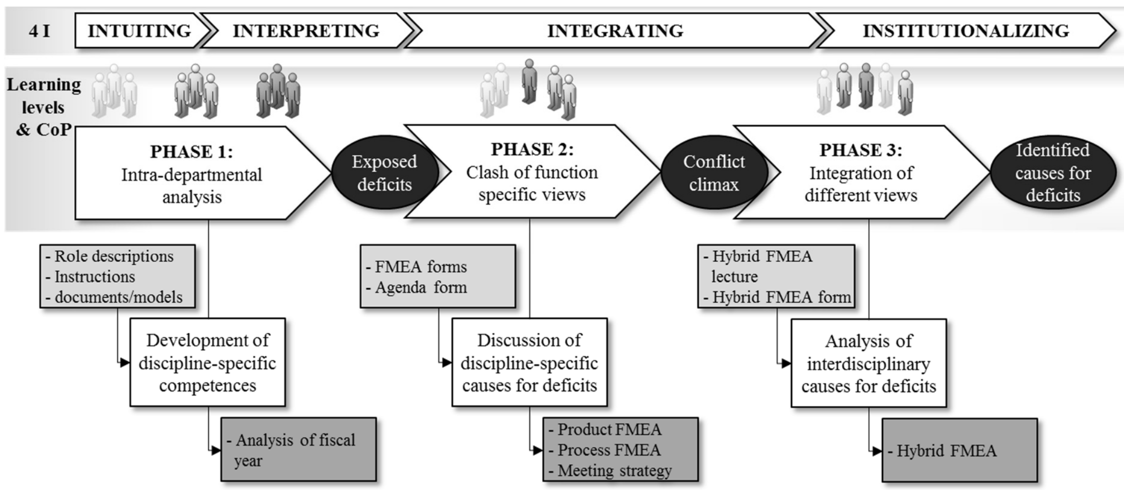

Figure 2. Procedure of the learning factory prototype

In the beginning the students are divided into four groups, each undergoing the same procedure simultaneously, supported and observed by one lecturer each. Every group consists of five members: two students with previous knowledge from the course ‘networked production systems’ to take the role of production employees and two students with previous knowledge from the course ‘fundamentals of product development’ to act as engineering product designers. Since the fifth student takes over the role of the project manager, he/she ideally studies SEPM, because in this subject management skills are more focused than in ME. The students are asked to empathize with their roles as much as possible during all phases of the upcoming game.

3.1 First phase: Intra-departmental analysis

A company that develops and produces percussion drilling machines provides the setting of this business game. The first phase serves for the individual students to identify with their role and to get sufficient insight into the work of "their" department (micro-level). To foster focus on their dedicated tasks the departments are spatially separated from each other. Every participant is handed out a role-specific task sheet with key questions as well as descriptions of the initial situation and of their role, complemented with typical characteristics which are almost caricaturally exaggerated to harden the fronts between the departments right at the beginning.

The product development group is provided with technical drawings and a CAD-model of the product (Figure 3a). Furthermore, a real drilling machine, which has to be disassembled, and the manual shall help to understand the functionality of this product. Finally the students need to sketch a construction model to enhance the gained comprehension of the functionality by then.

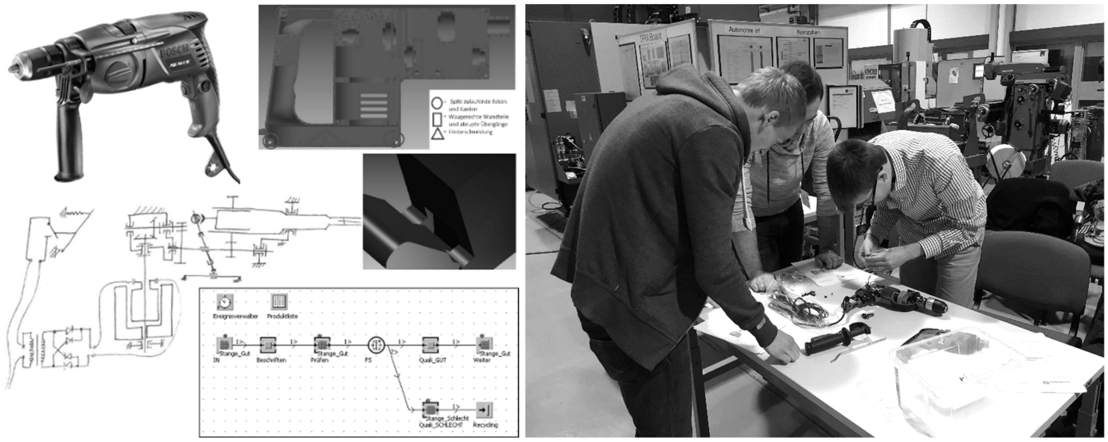

Figure 3a. Examples for the models and simulations;
3b. Students reassembling a dismantled drilling machine

The production department has to analyse the processes of production and assembly by using a virtual material flow model. A dismantled drilling machine has to be reassembled (Figure 3b) to reproduce and understand this process and also to consider critical steps. After the analysis together with their partners all employees of production as well as of product development have the opportunity to consult within their own department and compare their results. The described tasks are intended to develop the necessary competences in the specific disciplines for the next phases, which will be initiated by the project managers.

The project managers receive financial reports and customer feedback about the drilling machines sold over the previous fiscal year. This information has to be used to identify quality deficiencies and excessive manufacturing costs as major problems, which shall also be discussed in a joint meeting with both departments to improve the value-chain with a holistic approach. Therefor the project managers have to issue a meeting invitation describing shortly the issues they found and the intention of the planned meeting.

3.2 Second phase: Clash of function specific views

To be prepared for the discussion in the upcoming meeting (Figure 4) the employees are instructed to search possible reasons for the problems primarily in their own department (meso-level). The application of a product FMEA supports product development to identify quality-influencing components within the functionality and mode structure. A process FMEA is to be carried out by the production group to analyse cost-intensive steps within the manufacturing process.

The project managers are encouraged to quickly find solutions, which is intensified by the announcement that the management board will join the meeting too. So the project managers have the task to visit both departments to subliminally control the employees' progress on finding causes and thereby emphasizing the importance of the meeting. Confronted with this pressure and in order to protect the interests of their own departments (prevention of additional work or even dismissal), the employees are instructed to search for potential deficits the other department is responsible for. Knowing that the representatives of both departments will naturally try to move the focus from their own to the failures made by the "opposing" department, the project managers have to structure the meeting and elaborate a strategy to handle the conflicts (dilemmas). From his/her point of view not the causes are to be relevant but solutions. Therefore he/she has to bring an exploded view drawing of the drilling machine and a description of the manufacturing process to illustrate the problems and confront both parties with them. The project manager is instructed to pay attention to interface problems between both departments and possible deficits in coordination.

Figure 4. Joint meeting in presence of the management board

For the meeting (macro-level) it is important that the participants remain in their roles to increase the potential conflicts between the departments. The aim is to emphasize the difficulties of solving problems when each party sticks solely to their own views and goals.

3.3 Third phase: Integration of different views

The third phase starts with a feedback round where all participants reflect and discuss the problematic interaction during the first two phases. The lecturers then introduce the hybrid FMEA as an exemplary method to enable a better cooperation by integrating the views of both disciplines. Afterwards the students meet again in their interdisciplinary groups to discuss the cost and quality problems once again (macro-level). But this time they draw in experiences and the previously learned hybrid FMEA to analyse and solve the problems specifically at the interfaces in a collaborative instead of opposing way. The aim of this phase is to show the students that different views on engineering problems can cause conflicts and how interdisciplinary cooperation between different engineering functions can be supported by methods with a mutual approach. Another point is to demonstrate how team work benefits from the common basis and "language" these methods offer. Using the hybrid FMEA specifically guides the students to focus the analysis on the interdependencies between product development and production and create "failure trees".

At the end of this phase the new experiences are discussed again in the whole group. Especially the logical chain of failure-cause and troubleshooting that affects product development and production as well as the main barriers are subject of the reflection.

4. Reflection and discussion

By introducing the new approach in an early concept phase (prototype) we had the opportunity to verify the students' learning effects due to this format of curriculum. The participants evaluated this learning factory prototype as a very instructive experience because they had the opportunity to simulate a 'realistic' work situation which reaches far beyond the theoretical knowledge conveyed in lectures. The

combination of the tasks at different interaction-levels with the reflecting discussions in the whole group at the end of each phase (4I and CoP) was assessed as very helpful. The boundary conditions as for example the tight schedule or small details like the attendance of the management board were felt to strengthen the 'realistic feeling'. Also the group sizes of five students as well as the distribution of roles were assessed as appropriate. Overall it can be concluded that the single phases have the same logical outcomes as previously planned in theory and that the tasks and specific characteristics of the different roles are well accepted and impersonated by the students.
Though the participants stated the characterizations being helpful to identify with the roles the lecturers perceive that the students had difficulties to remain in their role during certain conflict situations. This could be prevented by providing the role descriptions and specific behaviour instructions just before the meetings. But actually we deduce that describing the roles has the effect that the students implicitly know that their actions are wrong and that their characters are artificially enforced to fit to the concept. So it is necessary to elicit the characteristic actions by specific work situations in combination with incentive arrangements or threats instead. This can be realized by the support of a software-based business game which implements the evaluation of made decisions and their consequences for the role play. Also the initial presumption that this exercise has to take place over a longer time period was reinforced especially by the difficulties of the students in carrying out the three different FMEAs. Because an introducing lecture or a detailed description for self-study require more time, a more pragmatic solution could be to provide either more examples or predetermined failures in the FMEA form. Moreover, also different methods should be tested and evaluated in comparison to the hybrid FMEA. Besides the handouts have to be improved by means of clearer instructions to prevent misunderstandings that had to be answered by the lecturers throughout the prototype. This improvements and additions needs to be put into action in a next round of this learning factory and compared to the presented observations.

5. Outlook

The development of this new learning factory prototype is the first step towards an interdisciplinary curriculum over a whole semester which will be integrated in the existing lectures held by LPE and LPS. Students who specialize in one of both disciplines will be equally distributed to small project groups, each having the task to develop a real product and to design its manufacturing process limited by certain requirements and boundary conditions. Similar to the prototype the new learning factory will lead through the stages of mismatch due to non-coordinated actions and lessons in methods that enable an improved work progress by integrative cooperation afterwards. Another important part of this training will be a bigger focus on project management methods and skills that are essential to coordinate multidisciplinary teams with a holistic overview. The aim of the prospective semester project is not only the development of an interdisciplinary way of thinking but also a possibility for the students to apply the knowledge they gained during their studies and transfer it on a real and new problem. A further benefit for the students is the enhancement of their soft and social skills through their interaction in this kind of work group. The cooperation with the Tongji University in Shanghai further offers the possibility to build intercultural teams and thereby adds the aspect of internationally distributed work. The integration of other subjects on the campus (e.g. material science, management & economics, law) has the potential to expand the presented learning factory to a learning company.

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