THE LEARNING FACTORY

AN ANNUAL EDITION FROM THE NETWORK OF INNOVATIVE LEARNING FACTORIES

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DEMONSTRATION SCENARIOS FOR “INDUSTRIE 4.0” IN LEARNING FACTORIES – AN ACTION-ORIENTED APPROACH FOR TRANSFERRING

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Abstract
Digitalization and the interconnection of value-adding-processes promise a multitude of opportunities to increase the competitiveness of small- and medium-sized companies. This article presents the results of the research project „Effiziente Fabrik 4.0“, which transforms an already existing production setting of a learning factory by means of approaches of Industrie 4.0 into a digitalized production environment. Moreover it is shown how this retrofitted setting can be used for competency development in the context of Industrie 4.0 and how this vision can be holistically transferred to company practice through a competence center.

1 INTRODUCTION
Despite the often predicted change from an industry to a service based economy in Europe, the current situation paints a different picture. For example, 7.7 million jobs are related to the vicinity of German production. Other 1.7 million jobs exist in the production environment, for example in IT and logistics (Abele and Reinhart 2011). In order to address challenges such as rising product varieties and shorter product life cycles, new technologies emerge. These technologies rise the capabilities of embedded systems and thus enabling the transformation of current manufacturing processes into best practices in order to meet customer expectations. Such innovations in industry can be seen as the 4th industrial revolution (Kagermann et al. 2013) and are therefore referred to as Industrie 4.0. Regarding the technological trends the complexity and effort for developing, implementing and managing such production systems are expected to increase drastically (Anderl 2015). This is one of the main reasons why many companies in mechanical engineering and plant engineering field, small and medium-sized enterprises (SME) in particular, view Industrie 4.0 with caution and skepticism. The effort-benefit relation is not clear and a methodical approach for prioritizing measures is lacking. This situation causes an urgent demand for research and learning facilities to offer workshops, trainings and other events to meet the specific needs and production environments of SMEs. Methods and models are necessary which guarantee a lifelong target based and effective further training in industrial companies. In view of rising labor costs in the European economy, it also seems useful to develop approaches that allow competency development near the work process.

2 RESEARCH PROJECT “EFFIZIENTE FABRIK 4.0”
In order to remain competitive, it is crucial to enable companies to further increase production efficiency by using solutions of digitalization. With this project plan companies are said to be qualified, to improve the efficiency of processes, resources and employees with the attempts and methods of Industrie 4.0. The overall aims of this project are:

- to offer a realistic experimental test bed for methods and attempts of Industrie 4.0,
- to link production technologies with IT and communication technologies, to qualify companies to individualize those solutions
- to validate the potential of increasing efficiency of each solution
- to improve the visibility and competitiveness of the production and research site Hessen. (Abele et al. 2015a)
Since Industrie 4.0 was presented at the “Hannover Messe” in 2011, several demonstration centers for Industrie 4.0 have been established (Anderl 2014). However, most of them follow a greenfield-approach. The unique feature of “Effiziente Fabrik 4.0” project is the implementation of Industrie 4.0 concepts in an already existing company infrastructure with typical machining processes and a manual or rather half automated assembly line producing a pneumatic cylinder. This brownfield approach faces the same challenges as SMEs. The project started in the middle of 2014 with a consortium of twelve company partners and two research institutes. The following chapters show the project structure and the project’s results.

2.1 PROJECT STRUCTURE

The project consists of the four stages study, concept development, implementation of demonstration scenarios and the transfer of knowledge, see figure 1.

![Figure 1: Project structure „Effiziente Fabrik 4.0“ (Abele et al. 2015a)](image)

During the study, several good-practices in companies were identified, analyzed and structured. Through interviews and company visits concepts and solutions have been analyzed which are able to increase the efficiency by linking production technologies with information and communication technologies. In order to analyze the good-practice approaches in detail a framework has been elaborated which allows to categorize the approaches and to identify potentials for further activities in the context of digitalization.

The second project stage focuses on the implementation of selected good-practice approaches into the learning factory CIP (Center for industrial productivity). The selection is based on the results provided by the framework and the industrial partner’s evaluation. This procedure led to the development of so called “Use Cases”. A Use Case is a description of a restricted work situation related to a certain application. Actions and circumstances are determined which are necessary for a process to take place. Each Use Cases aims at increasing the efficiency of the focused production system through the integration of information and communication technologies. Technical and organizational aspects have been addressed in accordance. Especially the strategy for networking was of high relevance. The main emphasis was on the conceptualization of a holistic and comprehensive IT-infrastructure as well as on the implementation and linkage of hard- and software related single solutions in consideration of existing production systems with:
• running and stable processes,
• existing resources and
• competencies of the personnel.

The Use Cases were implemented in the Process Learning Factory in close cooperation with the project partners. This step was followed by an organizational and economic evaluation based on the existing shop floor management system of the learning factory. Thus, a comparison of the primary to the Industrie 4.0-setting is possible. The knowledge transfer as well as the competency development consists of the transfer of the results and the findings of the projects through public events. Thus, a platform arises in order to present the findings of the study, the conceptualization and the implementation for interested companies and organizations. Furthermore the Use Cases and implemented solutions will be prepared didactically. These workshops will be integrated in the existing curriculum of the Process Learning Factory aiming at knowledge transfer to SMEs. This will build their competencies to tailor the use cases to meet this individual requirements and implement them. (Abele et al. 2015a).

2.2 DEMONSTRATION SCENARIOS WITHIN “EFFIZIENTE FABRIK 4.0”

The following good practices have been selected and developed into use cases.

Use Case “data management and usage of components as information carriers”

One of the main characteristics of the present manufacturing and management practices that many SMEs have in common are methods for data acquisition. Usually some kind of document-based processes such as reports, journals, tickets or any other protocol papers have been implemented and adjusted over time. Those methods often require manual input, that is difficult to integrate seamlessly with the manufacturing process itself. The resulting documents are usually kept stored on the shop floor or stored in offices.

To meet future requirements priority should be given to real-time applications for acquisition and processing of data, generated during the manufacturing process and if possible alongside the whole value chain. According to the vision of Industrie 4.0 those tasks should be performed digitally, without any media discontinuities and ideally fully automated by algorithms or components of the production system. In addition communication among all the systems and components participating in the manufacturing process is required. Additionally, an important issue will be the development of new methods for smart analysis and reasonable accumulation of gathered data to gain information of high value.

The interconnection and communication among cyber-physical systems is considered as the main technological approach for the vision of Industrie 4.0 (Anderl 2015). To put that kind of interaction into practice, related data sets and digitally compiled information have to be linked with the appropriate physical part or the work piece itself.

A way of implementation is to equip components with a label or a tag, to allow identification. Additionally, the tag provides a pointer to the digital information of the component, which is stored in a database. This approach enables the transformation of passive components into information carriers and allows to dispense with additional documentation and protocol papers. Finally, it allows to automatically recognize the marked object, be it a single component, a whole machine or even an employee and establish the desired connection to the appropriate digital data and information. The processing of data sets collected in that manner enables a deeper interconnection of distinct data points and a better overall analysis up to a real-time digital image of the shop floor. This promises a significant increase in transparency and better understanding of the whole production chain, which reveals the potential for efficiency enhancement.
Use Case “Condition Monitoring”

The main instrument of Industrie 4.0 is the enabling of a connectivity to various end points along value-adding-processes. Among others this offers a huge potential for existing and new condition monitoring approaches (Kagermann et al. 2015). To set the stage for this, it is necessary to integrate material, information and energy flows vertically as well as horizontally. With existent decentral intelligent components and a possible interconnection of them, using internet technologies, it is now possible to realize this cost-efficiently (Kagermann et al. 2015).

This use case illustrates different ways to assess data to obtain a real-time image of the process state. Particularly, the question how to interlink data from shop floor with the above-mentioned higher-level IT systems, retrofitting existing equipment economically, is answered. Targeting the brownfield aspect, this use case is based on a benefit-oriented approach, instead of a mere technological. The four steps of the approach follow the fieldbus neutral reference architecture for condition monitoring in factory automation (VDMA 2014).

![Figure 2: Procedure model for the use case “Condition monitoring”](image)

The benefit view, which describes the target dimensions, creates the overall aim for further implementation efforts. Typical dimensions are quality, speed or manufacturing costs (Abele et al. 2011). The second step is the functional view that consists of three hierarchical control levels (Wang et al. 2006) each addressing an identified target dimension. The first is the product level, focusing on product conditions. The second is the machine level, focusing on machine conditions. An the last is the process level, integrating the process status as well as the connection of machine and product data along the value stream. Knowing the functions, the question where to implement these functions has to be answered. Using an extended value stream analysis within the application view, digital wastes along the value stream can be identified. To eliminate digital wastes and to achieve the targeted functions, the automation view is finally added. At this stage the use case is implemented in hard- and software. Here the possibilities of Industrie 4.0 technologies are shown best.

Use Case “Flexible intelligent worker assistance system”

The role of employees in production is subject to constant change due to the implemented solutions and approaches of Industrie 4.0. The entire labor organization is especially influenced by the growth in real-time oriented control (Kagermann et al. 2015). The term “labor organization” includes the work processes, work contents and environments. This holds enormous potential for the empowerment of employees. One example are flexible intelligent worker assistance systems. The main goal of it is to assist employees with socio-technical approaches to design Industrie 4.0 solutions. To ensure this, a bidirectional communication between the system and the employee is required. On the one hand, the system adapts to the employee. It is able to offer him user-centered assembly work instruction, which is generated directly from the 3D CAD system, triggered by the component as an information carrier. On the other hand, the employee passes on his own knowledge of the system that learns from it. To be able to generate user-friendly assembly information, the worker assistance system requires various information concerning the employee. This information can include ergonomic parameters such as the body height, as well as skills such as knowledge and craft skills. For this purpose the employee data model was developed. At first the employee initiates the assistance system by logging in with his ID, see also Figure 3. As a result the system has access to the employee’s set of data. This is
followed by a scan and identification of the component. Subsequently individualised assistance can be provided. The assistance system now can provide assembly information such as time and quality numbers based on the component ID.

Figure 3: Worker assistance system, schematic procedure

The Use Cases as described need to be prepared didactically in order to support competency development of SMEs on all levels.

3 COMPETENCY DEVELOPMENT IN THE CONTEXT OF INDUSTRIE 4.0

3.1 COMPETENCY DEVELOPMENT IN LEARNING FACTORIES

Competencies are complex abilities for self-organization, which make it possible to respond to constantly changing complex environments with new behavioral strategies (Heyse and Erpenbeck 2009). Competencies can be built only through creative interaction when confronted with real, open and novel problem situations (Kuhlmann and Sauter 2008).

According to Dehnbostel, the field of work-related learning, and thus competency development, can be divided into work-based, work-connected and work-bound learning (Dehnbostel 2007). This classification describes the use of learning approaches in the range from afar the actual work processes to learning during the work process, see figure 4.
A well known and proven approach for competency development is the concept of the learning factory as a work-based approach (Abele et al. 2015b). Within this environment a real production setting is realized where the participants of workshops are trained on a real value stream. In order to develop competencies in an action-oriented way, besides theoretical lectures the taught methods are adapted to the production environment within practical exercises. The exercises start in a bad condition with a multitude of suboptimal solutions. The participants then improve this condition and thus develop competencies through creative interactions.

This concept will also be used for workshops in the context of “Industrie 4.0”. In order to transfer Industrie 4.0 holistically to SMEs and to develop competencies within this area, a competence center will be established in Darmstadt.

### 3.2 Establishing a Competence Center for “Industrie 4.0” in Darmstadt

The main characteristic of the here focused approach is its brown field application within an existing production environment of a process learning factory, instead of a green field application. This environment represents a typical production setting of a SME. Examining the value chain for the production of a pneumatic cylinder with a variety of process steps and an already implemented IT-infrastructure, the periphery of the situation at hand is not completely reinvented. In order to transfer the results on the research project “Effiziente Fabrik 4.0” and other “Industrie 4.0”-related research projects a competence center with focus on small and medium sized enterprises will be established. With
an interdisciplinary consortium consisting of research facilities, regional chambers, labor unions and other multipliers.

SME can not only be empowered in depth but also the transfer in width can be ensured.

In order to address the demands, a structural analysis of the region’s needs for action for SMEs and the craft sector in the context of digitalization has been executed. These requirements will be addressed in a demonstration a training platform for digital production and working processes.

The goal of the competence center is to increase the competitiveness of the SMEs by empowering them to recognize the opportunities of interconnectedness and digitalization, and to implement related concepts individually. The participants of the workshops should understand how they can link communication capable objects, based on available internet technologies, to increase the efficiency of their own value creation.

The analysis of the predominate industry-sectors in the region revealed the following fields of action (s. fig. 5): Efficient processes for value creation, labor 4.0, IT-security, new market opportunities and energy management.

The use cases of the project “Effiziente Fabrik 4.0” and the results of other current Industrie 4.0-related research projects are the starting point for the knowledge transfer. These and future demonstration scenarios will be integrated in the offered workshops by the competence center (e.g. identification of potentials in cost-effective production of customer-individual products, components as information carriers, risk assessment of data transmission in an internet-based cloud). In order to convey digitalization-related concepts appropriate to the requirements of SMEs, instruments for

- raising the awareness of the benefits (e.g. demonstrator in learning factories),
- analysis of potentials (e.g. approaches to Industrie 4.0 value stream mapping),
- qualification to implement in their own company (e.g. trainings in learning factories) and
- implementation and evaluation of the benefits and efforts of digitalization have to be developed.

By offering these instruments, the competence center meets the demands of the regional SMEs holistically from information to implementation of digitalization concepts in practice. The knowledge transfer in depth takes place in the learning factories based on the use cases (CIP, Center of industrial productivity, and ETA, center for energy efficiency) and test fields of TU Darmstadt. Thus, the participants are able to experience real operation situations within a test and demonstration environment and to evaluate the suitability for their own company. By target group-oriented offers, implementers, policy makers and multipliers are equipped with organizational, technological and labor skills. In order to not only empower in depth, the transfer in width will be ensured by involving regional chambers.

Figure 5: Structure of competence center for Industrie 4.0 at TU Darmstadt
4 CONCLUSION AND OUTLOOK

In the context of “Effizente Fabrik 4.0” relevant applications of Industrie 4.0 were identified in practice. These applications have been abstracted to a more general level and were implemented as use cases into the Learning Factory CiP. The didactical preparation of these demonstration scenarios within “Effizente Fabrik 4.0” ensures the knowledge transfer into companies.

The competence center will be established to offer particularly small and medium sized companies the possibility to recognize the benefits and opportunities of Industrie 4.0 solutions. Especially the concluding knowledge transfer and the didactical preparation of demonstration scenarios cover the demand on information and guidelines in the context of digitalization. Within the competence center the offer of Industrie 4.0-related trainings and other events will increase. Also the direct transfer of Industrie 4.0 solutions into the companies will be ensured through on-site projects.

5 LIST OF REFERENCES


LEARNING FACTORY CONCEPT TO IMPART KNOWLEDGE ABOUT ENGINEERING METHODS AS WELL AS SOCIAL SCIENCE METHODS

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Abstract
To counteract the challenging developments in the field of German manufacturing industry a comprehensive perspective especially for learning factories is needed. While in the past engineers mainly focused on the technological as well as organisational aspects, today the personnel aspect becomes even more important, since Industrie 4.0 relays on big data, data mining and cyber-physical systems thus interfering with the employees' personal rights. The work environment in manufacturing industries starts to change from manual tasks to planning and control and at the same time employees become more transparent, since assistance systems need to provide information to the employee demand-oriented. The following contribution will focus on the need for an additional content group within German learning factories, in order to provide a holistic view thus being able to train students, shop floor-, mid- and top-level employees as well as workers' representatives.

1 LEARNING FACTORIES FOR ENGINEERS
Learning factories have been developed to teach participants methods about process improvement. The advancements of learning factories during the past years show that it can be used to impart knowledge about very different topics. Abele has defined five content groups so far: production process, logistic processes, energy efficiency, design process, virtual/ digital/ organisation change. (Abele & Metternich, 2015) Most of the german learning factories have still an individual infrastructure and approach to these content groups. The initiative on European learning factories as well as the network of innovative learning factories (NIL) is trying to change that by developing standards (morphology) for learning factories. The purpose of learning factories (LF) has become as extensive as their contents. They are used for (academic) education, vocational training, for research, as transfer platforms and networking space. (Abele & Metternich, 2015) The first target group of german learning factories were students at universities. Nowadays, industrial participants (manager, shopfloor worker, worker in planning and control) are the second most important target group. (Kreimeier et al., 2014) The possibility to engage in processes within a real-world manufacturing environment allows the industrial participants to easily transfer problems to their own operational challenges.

The mentioned content groups mainly focus on the very technical aspects within the socio-technical stress field (“technic-organisation-personnel” or T-O-P). This circumstance is based on the fact, that the target groups are engineering students or industrial participant from different technical departments. Thereby the focus of the trainings is to impart knowledge about methods to improve the different aspects of the stress fiel of production systems (time-costs-quality).

On the basis of the changing requirements for employees in the production industry (employee data, data security, etc.) it becomes more and more important to consider the organisational and personnel aspects within next to the technical aspects. Thus the perspective of social science is needed for the development of learning factory modules. Along with the advancing requirements for modules towards social aspects, a new target group can be identified:
worker’s representatives. (Wagner et al., 2015)

The chair for production systems recognised the target group and content group a few years ago and entered a unique cooperation with the Office of Cooperation RUB/IG Metall (german: Gemeinsame Arbeitsstelle RUB/IG Metall). This unique started in the 1990s with interdisciplinary activities for works’ councils in the context of CIM (Computer Integrated Manufacturing) and has been extended since then. The basis for the close collaboration and the consideration of non-technological content within the learning factory trainings lies in the endeavors of the chair of production systems to relate teaching and research not only to technological and economic developments, but to consider it in the context of T-O-P.

The integration of the holistic view into learning factory programs at LPS started in 2011 with the interdisciplinary seminar “Management and Development of Labor” (MAO) for engineering students and for students of social sciences. Just like the learning factories in the beginning the LPS learning factory started out with an academic offer for engineering students. The training module allows the students to experience not only the technical aspects of improvements process but also the organisational and personnel affects. These modules are unique in Germany and have been expanded to the new target group of workers’ representatives in 2013.

2 SOCIALY EMBEDDED LEARNING FACTORY

To counteract the challenging developments in the field of European manufacturing industry, a comprehensive perspective on the socio-technical stress field T-O-P is required. In order to maintain and increase their competitiveness, enterprises are forced to optimize permanently their activities in all relevant stages. This includes four different transformation areas (see Figure 1): the financial system, the product system, the technical system and the personnel system. The perspective of the enterprises’ financial system deals with main questions about the return on investment (ROI) (WHY?). The product perspective focusses on return on sales (ROS), customer satisfaction and stresses issues such as product structuring and market strategies (WHAT?). The technical system’s point of view puts emphasis on the production system and business processes of firms (HOW?). Finally the personal system’s perspective (WHO?) characterizes out the integration of all employees’ issues such as human resource management, employment and working conditions and and qualifications as a embedded part of Industrial Relations System (IRS). This WHO-Perspective stresses out the topic of political, civil, and social rights at the workplace and recognize these as fundamentals of Industrial Citizenship in all member states of the European Union (EU) (Marshall 1963, Müller-Jentsch 2008).

Therefore the financial and product perspective of enterprises mainly consider economical aspects and are placed in the area of business administration and management.

Figure 1: socially embedded factory (Wannöffel, 2015)
Beside these economical aspects the LPS learning factory focuses on the technical and the personal systems’ perspective and aims at integrating them into a comprehensive analysis of the corporate development processes. This unique selling point is imbibed in the long lasting collaboration between the chair of production systems (LPS) and the Office of Cooperation RUB/IG Metall, which started in the 1990s. The approach is rooted in the idea that innovative development processes of enterprises are always socially embedded in a specific set of national institutional rules, standards and legal frameworks. These institutional frameworks differ depending on the national surroundings. Even in Europe it can e.g. differentiate between four general IRSfre: the “Nordic System” with strong influence of unions at the workplace as in the northern countries of Europe like Sweden, the more liberal market oriented “Angelo-Saxon System” as in Great Britain, the “Continental European System” with duality between unions and the strong influence of independent works’ councils as in Germany and the more political “Pluralistic System” as in southern countries of Europe (Wannöffel et al. 2007). Because of the specific national shapes of Industrial Relations and their impact on enterprises’ scopes of action, the approach of a socially embedded factory plays an important role in the education of each target group a learning factory addresses.

While the LPS contributes its expertise in tools, techniques and methods to optimize production systems (HOW?), the Office of Cooperation RUB/IG Metall adds competences regarding workers’ participation rights at the workplace as part of Industrial Citizenship (WHO?). This means in particular the impact on technological and organisational changes on the employees on company level on one hand, e.g. on workplace, job content, working time, wages, qualifications and further education, questions of employees’ participation and information rights and business agreements. On the other hand the Office of Cooperation RUB/IG Metall also includes questions on corporate level, such as collective agreements and legal frameworks as the German Works Constitution Act. Concerning current discussions about the forthcoming fundamental technological and organisational changes in context of Industrie 4.0 and the digitalization of industrial production, this extended view is becoming more and more important. In the recommendations of implementation for the “Future Project Industrie 4.0” acatech (Deutsche Akademie der Technikwissenschaften) underscores that actions of innovations shouldn’t be solely focussed on the accomplishment of technological issues, but also extend the view on an intelligent organisation of work and the employees’ competences (Kagermann et al., 2013, p. 56). The scientific community struggles with assumptions about how digitalization and increasing automation will impact the labor market. As a result diatematical prognoses are discussed. Optimistic scientists assume that the German labor market will benefit from the developments, while pessimists forecast a loss of almost 50% of the jobs (Pfeiffer/Suphan 2015, p. 4). The pessimistic view is based on the assumption that standardized work will be replaceable. The sociological point of view doubts that and stresses the necessity of shaping the possibilities connected to the technological changes (Pfeiffer/Suphan 2015, p.12). In context of the German system of Industrial Relations the institutional framework for shaping the impact of digitalization is located at the triangle of basic elements of workers’ participation rights: co-determination, consultation and information. The Office of Cooperation RUB/IG Metall sees shaping the processes of digitalization as the essential task for employees’ representatives. Besides the positive effects employees’ participation has for the employees themselves, including employees in change management also benefits enterprises economically. The implementation of new technologies and organisational processes in context of Industrie 4.0 won’t be realizable without the employees’ experience based know-how and their volition to cooperate. That’s why issues of employees’ qualifications, further education, job contents, the organisation of work, wage classification etc. are integrated in training concepts for socially embedded learning factories.

3 TRAINING APPROACH FOR ENGINEERING AND SOCIALLY EMBEDDED LEARNING FACTORIES

The new learning factory content group combines different teaching methods such as lectures, role plays and simulations as well as technical, non-technical and interdisciplinary contents. Representing the comprehensive view, it includes four different simulations at learning factory: two simulations focus on organisation-technic problems (e.g. customer dissatisfaction, bottleneck inside the production, etc.), while the other two focus on the labor-oriented
The changing requirement of the manufacturing industry calls for the development of a new content group and an expansion towards new target groups. An outline for an engineering and socially embedded learning factory concept was presented. Until the concept can be fully validated by further studies, the successful qualification of employees’ representatives during the past two years shows good results.
5 LIST OF REFERENCES


MACHINE DESIGN USING THE TEACHING FACTORY PARADIGM

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Abstract

The Teaching Factory paradigm aims to align manufacturing teaching and training standards to the needs of modern industrial practice. Future engineers and knowledge workers should adopt new teaching curricula in order to be prepared to cope with the increasing industrial requirements of the factories of the future. This paper presents the practice of Teaching Factory on a machine design industrial problem. The educational approach for the facilitation of the two-way knowledge communication is presented. This was a collaborative case between an academic lab that carried out the design work and a machine shop that provided the industrial problem. The conclusions of this study have shown that the Teaching Factory can provide students and research engineers with a real-life environment in order to develop their skills and comprehend the challenges involved, in collaborative design operations, carried out in everyday industrial practice.

1 INTRODUCTION

Manufacturing enters a new era, where blue-collar workers and engineers will need novel life-long learning schemes to keep up with the rapid advances in production related technologies, tools and techniques. Considering the importance of manufacturing as a wealth generating activity for any nation, the promotion of excellence will become a strategic target in the years to come. Manufacturing education will comprise a major driver towards that direction. However, teaching and training have not kept pace with the advances in technology. The current practice is deficient in providing the workers with a continuous delivery of engineering competencies and strong multi-disciplinary background. In addition, the lack in soft skills in comparison with IT skills has been widely acknowledged by employers (Tether et al. 2005). The innovation performance needs boosting. Even though innovative ideas and research outcomes are abundant, their transformation into new products and processes is mistreated. Modern concepts of training, industrial learning and knowledge transfer schemes can contribute to improving the innovation performance of European manufacturing (Chryssolouris, Mavrikios & Mourtzis, 2013). Nonetheless, manufacturing is a subject that cannot be treated effectively only inside a classroom, whilst industry can only evolve through the adoption of new research results.

In the last decade, the Teaching Factory concept has gained major interest, especially in the US, resulting in a number of educational and / or business pilot activities. Many educational institutions have tried to bring their educational practice closer to industry (Chryssolouris, Mavrikios & Mourtzis, 2013). Industrial projects that take place in the Teaching Factory provide students with the integration of learning experiences into a contextual setting, where emphasis is given to competency and effective application. Popular topics for Learning Factories include energy efficiency optimization and lean management of production processes and methods (Dinkelmann, Riffelmacher & Westkämper, 2011). Most of the reported applications of the Teaching Factory paradigm simulate the key features of an industrial environment in an academic setting, using model production equipment (Wagner et al., 2012). A drawback of these approaches is the fact that the dedicated production equipment, which is installed on the academic settings, can soon become obsolete. The pace in which production systems evolve has significantly increased over the last decades in order for shorter product lifecycles, imposed by the world markets to be met.
It becomes obvious that new approaches are required for manufacturing education in order to i) modernize the teaching process and bring it closer to the industrial practice ii) leverage industrial practice through new knowledge, iii) support the transition to the future knowledge workers and shorten the gap between resource-based manufacturing (labor and capital) and knowledge-based manufacturing (information and knowledge) and iv) establish and maintain a steady industrial growth. At conceptual level, an extended Teaching Factory paradigm, based on the knowledge triangle, has been suggested (Mavrikios et al., 2011). The aim is to effectively integrate education, research and innovation activities into a single initiative involving industry and academia. Towards that end, the proposed Teaching Factory paradigm focuses on integrating industry and academia, through novel adaptations to the teaching / training curricula, achieved by the deployment of ICT-based delivery mechanisms.

The Teaching Factory concept aims to become a new paradigm of both academic and industrial learning (Chryssolouris et al., 2006). The mission is to provide engineering activities and hands-on practice under industrial conditions for university students, while taking up research results and industrial learning activities for engineers and blue-collar workers. The concept of the Teaching Factory has its origins in the medical sciences discipline and specifically, in the paradigm of the teaching hospitals, namely the medical schools operating in parallel with hospitals. It aims to integrate the learning and working environments, from which realistic and relevant learning experiences arise. The “factory-to-classroom” concept of the Teaching Factory aims at transferring the real production/manufacturing environment to the classroom. The real life production brings knowledge, existing in the processes of every day industrial practice, through delivery mechanisms that allow the students to apprehend the production environment, in full context (Rentzos et al., 2014).

The implementation of the Teaching Factory is carried out through the adoption of an industrial project, in the context of academic practice. The intention is that the industrial and academic practices be brought together, in overlapping time and context. This problem will be deriving from a specific set of tasks, included in the product / production lifecycle. For example, an industrial project can focus on the line balancing of a new production line, which is normally carried out, in industrial practice, during the detailed engineering phase. The students work on finding a solution to this problem, by using modern ICT technologies for their communication with the engineers and tools, necessary for the development and validation of their ideas and solutions. The project is supported by an educational approach that integrates the details and logistics into the academic practice, together with an ICT approach that facilitates the interaction between a factory and a classroom.

The integration of the Teaching Factory industrial project into the academic practice is made through a weekly cycle of sessions, comprising supporting classes, project work and live interactions with the factory (Figure 1). Each “Teaching Factory” session that includes discussions, sharing of presentations, live videos from the production and other knowledge delivery mechanisms, depending on the content of the problem, is characterised by live interaction with the factory. During supporting classes, the student teams brainstorm their next steps in order to come up with a solution. The supporting classes are moderated by an academic supervisor, who is also responsible for triggering the discussions and providing guidelines in search of solution paths. Each member collaborates with the rest of his/ her teammates or even with the other teams. This educational approach has a two-fold objective. Firstly, it aims to integrate the need for live interaction with the factory, via tools and practices available in the academic environment and secondly, it allows and encourages certain soft skills to be developed and exercised among the students.
The real-life operation from the factory needs to be virtually presented to the university group of engineering students, who undertake the industrial project, using ICT tools. The students are able to interact with the engineers in real-time, ask questions and discuss their initial ideas to come up with solutions. The teaching staff member records the session, enhances it with appropriate annotations and holds a couple of coaching sessions with the students to elaborate their understanding even further and thus provide directions. The communication and interaction during the Teaching Factory sessions, between the factory and the classroom, are facilitated by web-based meeting tools for the sharing of presentations and videos.

2 MACHINE DESIGN CASE

Multi technologies Platforms (MTP) combine several functionalities in order to be able to extend their capabilities of a single manufacturing station in terms of flexibility. The industrial problem given for the presented Teaching Factory project, involved the case of designing a multi-technology platform that combined a milling working center with a robotic arm, equipped with a laser head (see Figure 2). The machine has the ability to perform simultaneous operations over two workstations. This hybrid machine layout had to be equipped with a swivel table in order to extend the capabilities of the machine. However, the simultaneous application of thermal loads and vibrations affect the machine’s performance in terms of dimensional accuracy and stability, due to the propagation of vibrations. Therefore, students that participated in this Teaching Factory project had to design the swivel table, in collaboration with the machine shop, where the MTP would be installed. The industrial requirements were given in the form of specifications referring to the static compliance, thermal load and dynamic compliance of the final product. Indicatively, the design had to eliminate any Eigen frequencies in the area of 150-250 Hz, while the first Eigen-mode had to be above 30 Hz.
3 TEACHING FACTORY COURSE

The Teaching Factory course aspired to solve the industrial problem, presented in the previous section. It was organized in five collaborative cycles, through which the students would interact with the machine shop in order to solve the problem, following the design cycle of the particular industrial practice, as depicted in Figure 3.

During the first cycle of the Teaching Factory, the real-life industrial problem was presented to the students from the academia side. An introduction to the hybrid machine tool for metal processing was made through live interaction with the machine shop and the operational conditions were specified. The students were presented with an introduction of their work’s goal, i.e. the design of an alternative machine bed and the investigation of its static, dynamic and thermal behavior. In order to proceed with an initial design, both the operational conditions and the machine bed's prerequisites had to be determined. These requirements would set the boundaries and the limitations, according to which the alternative approach should be designed. Moreover, a modal and thermo-elastic analysis had to be performed. As a result of the interaction between the students and the machine shop, there was a definition of the prerequisites that would have to be taken into account. At the end of the first cycle, the required tools for the student teams were specified for the creation and evaluation of the first draft design.

The second cycle focused on the design specifications, based on the prerequisites of the first cycle. For the assignment of the most suitable material for the particular application, an evaluation matrix has been used. The feedback sent by the machine shop to the students, during the first two cycles, was used for the drafting of an initial design within the third cycle of the Teaching Factory. The performance factors and the respective weights were evaluated in a matrix in order for the specifications of the first design to be defined. The most important factor was thermal stability because the material for this application had to be resistant to significant thermal loads. The students concluded that Cast Grey Iron was the most suitable material for this application. As regards the table’s design, the students
presented three alternative designs along with an analysis for each one of them. Their advantages and disadvantages considering their cost, machinability and weight were presented. Following the interaction with the machine shop, an initial alternative design was selected for further analysis. Finally, the specifications (methods and software packages) for the simulations were determined. Transient thermo-mechanical simulation, modal and static analysis would be carried out with the use of the ANSYS software.

The fourth cycle was focused on the detailed dynamic and thermal analysis of the selected design. The modal analysis was conducted for the estimation of the design’s Eigen modes and frequencies. Finite element methods were used with a mapped mesh of 20 mm. Both tetrahedral and hexahedral elements were employed in order for the optimum approximation of the geometry to be ensured. Following the modal analysis, a comparison between the alternative design parameters was made in order for the most appropriate values of the final product to be determined. The static compliance has been computed by employing the thermo-elastic displacement of the thermo-mechanical simulation. As regards the dynamic compliance, a harmonic analysis has been performed for the estimation of a displacement value, under a sinusoidal force. The computed values of the compliances were in agreement with the pre-defined limits. Finally, during the fifth cycle of the Teaching Factory course, the students presented their product as a result of this collaborative design process.

4 RESULTS

After the completion of the Teaching Factory’s fourth cycle, the students enter the fifth and final cycle during which the product is finalized and the results are presented to the machine shop. Based on the results from the modal and thermos-elastic analysis, improvements were made for the design’s finalization. Figure 4 depicts the modal analysis carried out in the product’s final design.

![Figure 4: Final design – Modal analysis Eigen modes.](image)

After several iterations of the modal simulations, for the improvement of the design, the students presented their design (see Figure 5) that satisfied all of the initial requirements and specifications. More specifically, the design complied with all the dynamic, thermal, machinability and usability requirements, set out in the first cycle of the Teaching Factory course.

![Figure 5: a) Isometric and b) Front views of the final design.](image)
5 CONCLUSIONS

The Teaching Factory course presented here, involved a team of students from academia and a machine shop that exhibited an industrial problem on product design. Specifically, the problem had to do with the design of a machine tool to be used in a multi-technology platform of a machine shop. Since, laser and milling processes would be taking place simultaneously, several static, dynamic and thermal constraints had to be satisfied during the design. Having followed a five cycle process, the students managed to develop the final design, in cooperation with the machine shop, under real-life industrial practices. The industrial problem, in hand, was complicated and the students had to respond with minimum simplification during their design and analysis work, as is the case in industrial practice. Through the iterative interaction with the machine shop, the students ended up with a design that complied with all the given requirements from the machine shop’s side. Finally, the feedback that the students received, through a questionnaires, regarding their participation in this Teaching Factory course, indicated that it was perceived as a valuable knowledge experience due to the real industrial problem encountered. The engineering procedure revealed to students some realistic aspects concerning the industrial practice for product design. From the stage of the problem identification and up to the evaluation of the results, the students were faced with several challenges, which they managed to overcome through their interaction with engineers, at the machine shop and the support of academic personnel. The students were able to develop their skills even further, through the demanding collaboration, the need to structure efficient workplans and the preparation of technical reports.

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6 LIST OF REFERENCES


A SEAMLESS CONVERGENCE OF THE DIGITAL AND PHYSICAL FACTORY AIMING IN PERSONALIZED PRODUCT EMERGENCE PROCESS (PPEP) FOR SMART PRODUCTS WITHIN ESB LOGISTICS LEARNING FACTORY AT REUTLINGEN UNIVERSITY

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Abstract
A seamless convergence of the digital and physical factory aiming in personalized Product Emergence Process (PPEP) for smart products within ESB Logistics Learning Factory at Reutlingen University. A completely new business model with reference to “Industrie 4.0” and facilitated by 3D Experience Software in today’s networked society in which customers expect immediate responses, delightful experience and simple solutions is one of the mission scenarios in the ESB Logistics Learning Factory at ESB Business School (Reutlingen University). Instead of traditional ways of working and a conventional operating factory real workers and robots work semi-intuitive together. Centerpiece in the self-planned interim factory is the smart personalized product, uniquely identifiable and locatable at all times during the production process – a scooter with an individual colored mobile phone – holder for any smart phone produced with a 3D printer in lot size one. Smart products have in the future solutions incorporated internet based services – designed and manufactured - at the costs of mass products. The starting point was the physical ESB Logistics Learning Factory which has been extended with the digital cloud-based factory. A summary of the results are basic seminars for the digital software tools, a research proposal for infrastructure, and the setup of a concept for the back coupling of the real changes in the factory into the digital ESB Logistics Learning Factory.

1 INTRODUCTION
The rapid pace at which the world turns today and more importantly will turn in the future – think about the year 2050 (born as from 1980 Gen Y and 2000 Gen Z), certainly poses risks, but offers at least as many great opportunities, because a customer wish or a brainchild born today can be turned into reality in a very short time span. The next generations (latest Gen Y and Gen Z) want to create, customize and change – and they have the ideas and digital native knowhow to do so. They hardly differentiate between the virtual and real world; it is simply a seamless transition. Eminently, the rising multiple technical options will induce people to control things faster and in a better direction, and these are the driving factors behind the new business model of a seamless convergence of the digital and physical factory aimed at a personalized Product Emergence Process (PPEP).

One of these new technical options is the 3DEXPERIENCE business platform of Dassault Systèmes. It provides software solutions for every business segment in the company, from marketing and sales to engineering, and helps companies create differentiating consumer experiences in their value creation process, by means of collaboration, dash boarding and 3D visualization as speech. The App-based end to end cloud software V62015X is the platform used in the ESB Logistics Learning Factory. The “customer wish” is the smart personalized product - a scooter with an individual colored mobile phone – holder with its own energy supply for any smart phone, produced by additive manufacturing with a 3D printer. Additionally, the scooter is equipped with a retrievable declarative product memory. Monitoring and control is handled by sensor tags and a Raspberry Pi 2 positioned on the product. The engineering design and implementation of the changeable, real and flexible production system is guided by a self-execution system with intelligent conveyor belts that independently finds, amongst others, esplanade workplaces (Wegener, 2014).
2 NEW BUSINESS MODEL WITH REFERENCE TO INDUSTRIE 4.0

Intelligent products, high customization of products, flexible production, highly qualified professionals with a much broader knowledge base, demographically-sensitive job design and individualization of customer requirements are all tags of “Industrie 4.0”. Society is on its way, with large steps, to the fourth industrial revolution = “Industrie 4.0”. This announces a technologically advanced industry by means of complex cyber-physical systems, distinguishing between intelligent products and beyond smart factories (Scheer, August-Wilhelm 2013). Cyber-physical systems are networked systems that act autonomously and remodel the entire value chain of products. Together with cloud computing, cyber-physical systems are the cornerstone of the fourth industrial revolution (Marktplatz Mittelstand GmbH & Co. KG (URL) 2013). In this area, employees are part of a new business model, working in office 21 room zones with digital tools, networked worldwide, handling the data on cloud systems, designing and implementing in the digital world before transferring it into the physical environment, using agile project management methods and creating smart individual products and flexible intelligent factories all in order to speed up the customer delivery process.

2.1 3D EXPERIENCE PLATFORM

The 3D Experience platform of Dassault Systèmes is a possible software solution supporting new business models with reference to “Industrie 4.0” implemented in the ESB Logistics Learning Factory- digital engineering environment. 219 roles such as that of a “contract deliverable manager” or “visual experience designer” are integrated with special functionalities.

Customer requirements grow immensely. The consumer is in focus and his future relationships to product and render services. The 3D Experience Software is tailor-made for this changed customer behavior. The customer determines the product. The customer experience journey starts with idea generation then proceeds to product choice and last but not least ends with the purchase decision. C2B, customer to business is clearly represented.

Figure 1: Surface of cloud based 3D experience software

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Figure 2: Content of cloud based 3D experience software
### 2.2 RESEARCH QUESTION

The research question, which was supposed to be answered, can be divided into three sub-questions, out of which the first one is rather an applied research project:

**First:** Can the implementation of a seamless transition between the digital and physical factory accelerate the delivery lead time for personalized products?

**Second:** Can students and/or seminar participants gain knowledge and skills about the chances and requirements of planning, implementing and maintaining a seamless convergent digital and physical factory in time-limited seminars?

**Third:** Digital Twin - are software and hardware systems nowadays are able to image a product in all its aspects and surroundings in a comprehensive representation of a completely identical virtual image of the reality?

### 3 PERSONALIZED PRODUCT EMERGENCE PROCESS (PPEP) FOR THE SMART PERSONALIZED PRODUCT, DEVELOPMENT AND MANUFACTURING

The customer requirements alone were crucial for the development of the product, the scooter with two individual components namely a cell phone holder with its own power supply, and a retrievable declarative product memory. For the mobile phone holder, 4 different colours and 32 possible phone designs by Apple, Nokia and SAMSUNG were given as guideline alternatives. The product memory should be placed on the scooter and the information gathered should be clearly visibly available. To achieve these goals the phone holder was constructed in CATIA V6 with parameterization in the form of a design table and manufactured with a 3D printer Ultimaker 2 Extended. The active product memory was programmed on a Raspberry Pi 2.

![Development and additive manufacturing of the personalized product](image1)

**Figure 3:** Development and additive manufacturing of the personalized product (left)

**Figure 4:** Real product scooter with cellphone case holder and active product memory (right)

### 4 DIGITAL AND PHYSICAL ESB LOGISTICS LEARNING FACTORY

The ESB Logistics Learning Factory (LLF) is equipped with a continuously integrated product and process planning environment (so called “Engineering & Operations Cockpit (EOC)”) as well as various kinds of physical infrastructure, allowing for the design of realistic work and logistics systems. Based on the defined products and customer orders this learning environment allows the participants to plan, validate, realize and optimize a production system holistically. The “EOC” relies mainly on tools for product and process engineering as well as for operations management.
4.1 DIGITAL ENGINEERING PROCESS

Project initiation
Nowadays, the customization of workflows regarding “Industrie 4.0” principles has already started. For a working scenario in the LLF, the idea was posted in the social network App 3DSwYm and proven as an idea portal online. Change of information across organizations, with a focal point on knowledge and value creation, communities for interdisciplinary communication and the transfer of data for each member takes place in this App.

Project creation
The scooter project was generated in the project management APP of ENOVIA. Project decisions and controls, targets, schedules, milestones, contract contents as well as chat and collaboration functionality was performed therein.

Product design and individualization by parametrisation
The design data of the scooter was migrated and opened in the design App of CATIA from a legacy V6 system with a 3DXML file. The parameterized cell phone holder was designed with a design table in a construction App of CATIA.

Process planning
The assembly processes were loaded in the process planning App of DELMIA. The labor system was automatically created with stations and jobs in the line with the EBOM. The MBOM is generated when assemblies are combined and the product is linked to the process. The design phase of the 3D layout was executed in the plant layout application by implementing resources, workers, conveyor belts etc. partial from catalog libraries. The time analyses for the operations were defined with the UAS process with the time analysis App. The line balancing is automatically calculated in the workload balancing App. The shoring simulation of the product is launched on the Play button in the compass of the software and determines the assembly or the traverse tracks. The simulation of the working system was initiated in the process planning App after the definition of the precedence relations and passing direction. The work instructions for the blues were generated with film sequences and their respective screenshots with marking in the work instructions App. In addition, utility films were used at the workstations. To ensure an improved support of changeable production scenarios and decentralized control structures (Schenk, Wirth, Müller, 2014) a cloud-based so-called “Self-Execution System (SES)” framework has been developed in cooperation with the IT company BECOS.

Plant layout
The factory layout was generated in the plant layout App by using self-constructed objects and catalog objects.
Material flow simulation

One way to simulate the material flow in the factory and to obtain key figures for the production was realized with the material flow app. A data model was initially developed afterwards the corresponding information model has been derived.

![Digital Factory represented in the 3D Experience software with data model integrated product, -process, -resource- and logistics view](image)

Figure 6: Digital Factory represented in the 3D Experience software with data model integrated product, -process, -resource- and logistics view

4.2 PHYSICAL LEARNING FACTORY

Following the focus of the LLF, a large variety of assembly and logistics infrastructure is available for the participants to implement and optimize production systems.

Assembly system

A modular pipe construction system can be used by the learners to build various kinds of customized physical infrastructure such as assembly, quality check and packaging workstations. All installations can be reconfigured or optimized easily, e.g. to resolve ergonomic issues identified by the learners during the workshop. Since all workstations are mobile and equipped with wireless communication technology and accumulator batteries, there are no limitations regarding changes to the factory layout. The workers at the assembly stations can use mobile tablet-pc’s, e.g. to receive orders, to send information back to the planning system, to access multimedia-based work instructions or to analyse specific production processes. The access or feedback of information can take place manually or automatically, e.g. by using RFID-technology embedded on the product itself or on the jigs. For storage purposes, racks for boxes and pallets can be created using the modular pipe system already mentioned. Besides manual pallet trucks and transport trolleys, different kinds of autonomous guided vehicles (AGVs) as well as an intelligent continuous conveyor system are available for material transport. By means of the plug-and-play functionality and local control units in each conveyor module, the modules can be combined to user-defined conveying lines without the need of a central control entity.
Human-Machine-Interfaces (HMI)

To automate specific process or to facilitate the work of the workers, two collaborative robots (“Rethink Robotics Baxter” and “Universal Robots UR10”) can be implemented into the work system. Through sonar and tactile sensors, these robots are able to collaborate with workers without protective fences. These robots can also be taught directly by moving the robot joints, which allows these robots to be integrated quickly for specific tasks directly by the worker. Learners are therefore able to experience the potentials and limitations of collaborative robots, which should not replace the worker but assist him/her in a practice-oriented manner and examine the effects of this technical assistance system on the capacities, throughput times or physical strain of selected work tasks. For more complex tasks, these robots can be also programmed via the open-source framework ROS.

Additive manufacturing technology

The realization of the product idea was achieved via the additive manufacturing process. The characteristics quality, process quality, temperature stability and building space were decisive for the purchase of two 3D printers. The model Ultimaker Extended 2 meets the requirements excellently and is also suitable for the living room, because the fused deposition modelling is very quiet. To implement the 3D printing process into the production scenario, the material – filament PLA (Polylactid), must first be determined. The optimal printing parameters were specified in the slicing software Cura. The printing time for the holder is approx. 6 hours and for the cellphone case approx. 15-18 hours. Thus, the bottleneck in the production is identified, keeping in consideration the period assembly of the scooter of about 7 minutes. The processes employed in the LLF are Rapid Prototyping in the product development phase and Rapid Tooling for the construction of mounting devices.

Figure 7: Physical ESB Logistics Learning Factory

4.3 DIGITAL TWIN

In the future, a significant position will become the capture, analysis and use of the resulting data in the context of Industrie 4.0. The widespread distribution of Embedded Systems, which is accompanied by the use of smart resources in operating systems, will deliver outcome in increased data availability along the considered process chain which forms the data basics for the “digital shadow”. The exact data image is at any time up to date in real time. For future improvement or further development of factory and process structures the reduction of planning and producing time for personalized products by digital engineering is providing a significant contribution to realize batch
size 1 economically. The required digital infrastructure based on a dynamic networked and adaptable ecosystem that combines cloud based bidirectional the digital and real world. The scheme behind it is a superior production system that knows which resources (tools, equipment, people, etc.) are available and which products can be processed at exactly this moment.

5 SUMMARY AND OUTLOOK

The experience of the projection of the first version of a seamless digital and real factory and the awareness of the research questions has taught the Logistics Learning Factory team to use a multi-staged qualification concept to enable the learner with the relevant skills and competences. This concept contains phases of self-study, instruction, practice and the self-dependent action and experience oriented application of methods within such a comprehensive and complex project in the learning factory. To manufacture the smart personalized product with over 100 variants by innovative ICT technologies and a hybrid intelligent production system concerning “Industrie 4.0” aspects showed a fast ramp-up and earlier real production scenario. Having extensive software systems like the 3D Experience platform with apps and predefined roles means a lot of preparation and knowledge and at least to have correct data throughout the entire process chain. Validation of the digital solution is mandatory and the structure of the real factory may still pose challenges which are not noticed in the digital world – e.g. consistence of PLA material. A cloud solution should be very carefully lit regarding legal framework of the hosting country, reachability, provider, back-up scenario etc. For goal oriented application, dedicated learning modules which will comprise of the digital engineering and physical production - the so called digital-physical -basis-scenarios -must be developed and filled with reference data. Future research projects will deal with providing acceleration of the personalized product creation by the use of seamless digital and real environments as well as with the development of methods and procedures for an automated back coupling of the physical factory into the “digital engineering world”. Basic seminars for the 3D Experience platform have to be composed of fast learning and easy to understand contents. The digital factory is actually expanded with finalization of the material flow simulation before the next steps like robotics follow. Further steps considered in a special way to the digital twins and the digital shadow with real - time feedback the entire learning factory will be equipped with sensors and other tags. Technologies which are no longer sufficient for the interconnectedness at real objects e.g. our trace ant will be replaced. Research proposals for infrastructure are tendered and last but not least the new building for the ICT - ESB Logistics Learning Factory is approved and construction start is planned for end of 2016.

6 LIST OF REFERENCES


http://www.3ds.com
THE DEVELOPMENT OF AN INDUSTRIE 4.0 IMPLEMENTATION FRAMEWORK WITHIN LEARNING FACTORIES

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Abstract
Globalization, outsourcing and resource scarcity have drastically increased the intensity of competitive manufacturing, forcing companies to deliver on higher expectations with less staff and minimal resource usage. This situation has ushered forth a new industrial revolution.

This new revolution, coined by the German government as Industrie 4.0, has given way to exponential advances in technologies. The implementation of these technologies should, in theory, enable firms to significantly reduce the negative impact of their operations on their triple bottom line and improve all operational efficiencies. However, whilst the implementation of these technologies provide seeming and logical improvements; how to implement, with what, and where is still largely unclear and can lead to total abolishment due to the lack of knowledge. Fortunately, learning factories are paving the way for teaching the fundamentals of industry related concepts within a controlled and direct goal orientated manner. They allow implementation of concepts so as to practically teach and provide understanding of theoretical ideologies.

The indirect application tool that is provided through learning factories, along with the large potential that Industrie 4.0 has to offer, leads to the idea of implementing an Industrie 4.0 environment within a learning factory to showcase the benefits of correctly implementing these technologies, whilst providing the basis upon which newer technologies can be implemented and tested. This paper will address the development of a framework that will act as decision support for implementing Industrie 4.0 within a learning factory, which is then validated with a use case at the ESB learning factory, Reutlingen University, Germany.

1 INTRODUCTION
The root purpose of any firm is to create value and turn a profit, and the manufacturing and production environments are no exception. In order to do so, it must be able to satisfy the demands and expectations of the customers. In a society driven by ever increasing higher expectations, customers have begun to expect and take certain quality standards as a given. In this competitive environment, it is crucial to meet the expectations and demands of customers, so as to retain customers’ goodwill and maximise sales. A company must therefore always seek to reduce input costs, while improving the quality of its finished products and goods.

In order to meet the increasing customer demands, companies are looking towards Industrie 4.0 as a solution. The implementation of Industrie 4.0 is expected to significantly reduce the negative impacts that a company’s operations have on their triple bottom line, whilst improving operational efficiencies. Although many companies have realised the potential benefits of implementing Industrie 4.0, how to successfully implement it remains unclear. The reason being that Industrie 4.0 is still very much theoretical and managers do not know how to approach and correctly implement it within their companies.

Fortunately, learning factories are paving the way for teaching the fundamentals of industry related concepts within a controlled and direct goal orientated manner (Kreimeier et al., 2014). They allow implementation of concepts so
as to practically teach and provide understanding of theoretical ideologies. Some learning factories have, since their inception, shifted and divided their focus, from a pure teaching tool, to industry leaders with regards to innovation and developments (ESB Business School - Reutlingen University, 2016).

The indirect application tool that is provided through learning factories, along with the large potential that Industrie 4.0 has to offer, leads to the idea of implementing an Industrie 4.0 environment within a learning factory to showcase the benefits of correctly implementing these technologies, whilst providing the basis upon which newer technologies can be implemented and tested. This paper will address the development of a framework that will act as decision support for implementing Industrie 4.0 within a learning factory.

2 LEARNING FACTORIES

2.1 BRIEF HISTORY

In 1994, the National Science Foundation (NSF) in the USA awarded Penn State University a grant to develop and establish a „learning factory“ (Penn State University, 2016). It was during this time that the term was coined and patented. It referred to an interdisciplinary hands-on engineering design approach with strong links and interactions to industry (Penn State University, 2016). This program run by Penn State University was awarded the National Academy of Engineering’s Gordon prize for innovation in Engineering in 2006. Since then, the use of learning factories has increased, particularly in Europe.

2.2 EUROPEAN INCEPTION

The increased use of learning factories was funded by the German government through the German Academic Exchange Service (DAAD) and the German Federal Ministry of Education and Research (BMBF) under a project called the European Network of Innovative Learning Factories (NIL) (ESB Business School - Reutlingen University, 2016). The goal of the NIL project is to significantly contribute to an internationally recognised standard of the learning factory, so as to support international mobility enabling innovative educational programs that will enhance the quality of existing and future learning factories.

The rapid increase of funding made available and the high success of the learning factories stimulated the academic world and became a topic of general conversation, which lead to its popularity as a research topic. The numerous research efforts have produced a variety of topics, ranging from the validation of the success of learning factories, to design and implementation methodologies, and improvement and expansion processes.

3 INDUSTRIE 4.0

The fourth industrial revolution, Industrie 4.0 is a very popular and extensively discussed topic in social groups, industry as well as in the academic field (Gregor, Matuszek, Medvecky, & Stefanik, 2009). Since its first mentioning in 2011 by the German government, it has become a top priority for many research centres, universities and companies, especially in Germany. The reason being, it has been estimated that the benefits of Industrie 4.0 will contribute as much as €78 billion to the German gross domestic product by 2025 (Bauer, Schlund, Marrenbach, & Ganschar, 2014). With the popularity of this topic as a research topic, and the fact that for the first time in history an industrial revolution is being predicted a-priori, academics and practitioners have obscured the true meaning and definition of Industrie 4.0 (Bauernhansl, Ten Hompel, & Vogel-Heuser, 2014). Although the true definition has been blurred, there still exist many overlapping criteria and details, upon which the framework, discussed in this paper, was developed.

Industrie 4.0 is a collective term for a high technological strategy, which aims to not only promote, but drastically improve computerisation and industrialisation (Schwab, 2016). Industrie 4.0, in itself is a term that combines and
captures contemporary automation, data exchange and manufacturing technologies. (Hermann, Pentek, & Otto, 2015) describes Industrie 4.0 as follows: “Within the modular structured smart factories of Industrie 4.0, cyber-physical systems (CPS) monitor physical processes, create a virtual copy of the physical world and make decentralised decisions. Over the internet of things (IoT), CPSs communicate and co-operate with each other and humans in real time. Via the internet of services (IoS), both internal and cross-organisational services are offered and utilised by participants of the value chain”.

4 Development of an Industrie 4.0 Framework for Learning Factories

Industrie 4.0 is not a method in itself, but a tool for the enhancement of current operations within an organisation. The framework was therefore developed, not only to provide decision support for the complete design of a new learning factory, with the focus on Industrie 4.0 (Greenfield design), but also for the redesign of already existing learning factories, that now wish to incorporate Industrie 4.0 with the elements that they currently have (Industrie 4.0 redesign). The third application of the framework is for already existing learning factories who wish to enhance their current operations with the addition of Industrie 4.0 applications (Industrie 4.0 Greenfield design).

For the development of the framework, the dimensions of the elements within a learning factory were broken down from its core competencies that are taught or Industrie 4.0 applications to the most basic, physical building blocks and associated enabling technologies. The dependencies between each of the dimensions, as well as the interdependencies of elements within a dimension were also defined.

4.1 Dimensions of Learning Factory Elements

The first dimension defined for the framework contains the competencies taught in learning factories, relevant to Industrie 4.0. A competency is in this case defined as; the development of a targeted, industry related, ability, which can be taught through various applications.

These applications form the second dimension, and are defined as an Industrie 4.0 instance, brought about by/ executed, or fulfilled by multiple methods.

The third dimension, method, is defined, in this case, as comprising up of multiple objects and system nodes that, together form a function. This is also the first dimension in the framework, where the user can take a single element and use it to perform a defined purpose.

System nodes are user instances which can be altered or changed in some manner to serve a purpose or function within a system process. They form the fourth dimension, and are the culmination of smaller objects. Objects in this case are the smallest physical element that can be a part of, enhance or alter a process function, but cannot be a process function on its own.

Technologies and software are the sixth and final dimension which are required for objects and system nodes to function properly.

The various dimensions are shown in Figure 1.
5 USE CASE

As a use case for the framework developed, the ESB learning factory at Reutlingen University, Germany was considered. Since the learning factory in question was already in existence and simply wanted the addition of Industrie 4.0 applications, the framework was applied as an Industrie 4.0 Greenfield design. However, since the learning factory already had many elements available, this Greenfield design was combined with an Industrie 4.0 redesign in order to best use what they already had.

For this use case, three Industrie 4.0 applications were to be included, namely:

1. Collaborative work
2. Intelligent transport
3. Smart manufacturing

These applications were individually broken down to the technologies and software required for correct functioning. Each of the relevant system nodes, objects and technologies were classified according to: Those already implemented; those available but not implemented yet; those required; and those which were deemed not feasible for the specific use case. An excerpt of the applied framework is shown in Figure 2.

When selecting which objects and technologies to introduce into the learning factory, the overlaps between the three applications were considered. It was found that the biggest effects could be realised through the addition of near field communication (NFC) technologies, communication protocols such as Ethernet and Wi-Fi, coupled with micro controllers and Wi-Fi routers. With the addition of these elements, collaborative work, intelligent transport and smart manufacturing could be showcased in the learning factory.
6 DEMONSTRATOR

As described in Section 5, the framework, applied to the ESB learning factory highlighted the focal areas that should be addressed in order to implement an Industrie 4.0 collaborative instance. These areas were analysed and a concept demonstrator was built using the framework result as a guideline.

The result of the concept demonstrator, was the incorporation of RFID work scheduling, via an Arduino equipped with an RFID reader and Ethernet shield. The Arduino was connected to a UR10 robot and sent the production details contained on the RFID card to the robot. This implementation allowed enhanced collaborative work, as the robot was programmed to be able to receive production details based on what has been written to the RFID card.

As the robot receives the production details, so does the human counterpart via a RFID enabled pick by light system, so the human and robot are able to work together. The human in this case, picks smaller parts that the robot can not grip and the robot picks the heavier ones. The robot cell within the collaborative workstation can be seen in Figure 4. The information flow of the robot cell within the collaborative working environment can be seen in Figure 3.
The other two Industrie 4.0 applications, smart manufacturing and intelligent transport, were achieved in a similar manner to the collaborative work application. Both making use of RFID readers and associated technologies.

7 CONCLUSION

The framework developed in this paper was successfully implemented for the ESB learning factory case, in which an Industrie 4.0 Greenfield design was combined with an Industrie 4.0 redesign. To further validate the framework, a second use case, namely the Stellenbosch learning factory, will be considered. This learning factory is not yet in existence and will therefore serve to validate the third application of the framework, namely the complete Greenfield design of a learning factory with focus on Industrie 4.0 applications.

8 LIST OF REFERENCES


THE “SMART FACTORY” AT MTA SZTAKI—A TEST, DEMONSTRATION AND EDUCATION PLATFORM FOR INDUSTRY 4.0 AND CYBER-PHYSICAL SYSTEMS CONCEPTS

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Abstract

The paper gives an in-progress overview of a facility being built up at the Institute for Computer Science and Control of the Hungarian Academy of Sciences (MTA SZTAKI) in Budapest. The key part of the paper explains various components and functionalities of the facility (both already implemented and under design/construction). In addition, a brief outlook is given on the role of the facility in the context of the Industry 4.0 and Cyber-Physical Systems concepts, as well as its potential in research and education.

1 INTRODUCTION

Recent years have witnessed accelerating and important changes in the manufacturing field as well as in other branches of industry, technology and infrastructure of everyday life. This is, on one hand, driven by the evolving demands of customers, users or environmental and economic factors calling for faster response, more adaptivity, increased fault-tolerance and higher resource efficiency of large-scale infrastructure, production and socio-economic systems (Rogalski, 2012). On the other hand, the development of sensing and communication technologies, computational resources and associated scientific and technological background for safe handling, sharing and efficient processing of information are now allowing increasing transparency of complex systems and processes (Stephan et al., 2013), so that more accurate planning, forecasting, early warnings, up-to-date tracking and comprehensive support for difficult decisions become reality. In this context, industrial production begins to unfold the concept of Industry 4.0 wherein process observability (Bauernhansl et al., 2014; Dais, 2014) and multi-directional interaction of autonomous virtual and physical system components and actors (Gorecky, 2014), also a characteristic of Cyber-Physical Systems (Shi et al., 2011; Sztipanovits et al., 2012), play an important role.

Recent research and development projects completed with the participation or coordination of the Research Laboratory on Engineering and Management Intelligence (EMI) of MTA SZTAKI have revealed that many characteristics of Industry 4.0 do address demands already recognized by the industry, and can be implemented in industrial production environments, also in co-existence with a number of “legacy” solutions. Nonetheless, findings also show that the current practice of building up complex solutions within dedicated environments for development, test, and simulation, often subject to binding confidentiality restrictions, do not optimally serve the spreading and awareness of such innovation in several regards:

- The possibilities of demonstrating innovative concepts in manufacturing to future adopters remains within the bounds of either an entirely virtual simulation of limited size and complexity, or depends on the willingness of past industrial partners to reveal the nature and realized benefits of successful innovation in real-life production processes. It is clear that in both cases, innovation outcomes, so much actual impact they have in the industry, may have to be presented in ways with far less convincing power than the known—and experienced—potential and merits of the solutions would amount to.
• A project-by-project approach to experiments and tests in research and development does not favor the investigation of aspects that do not lie in the spectrum of specific projects but may hold relevance in a scientific context, or have potential for future industrial application. The examination of such problems is much facilitated by an experimental environment that is largely independent of projects with a definite target.

• A research institute closely collaborating with higher education must also serve the objective of raising proper awareness of the general public regarding challenges, potentials and developments in today’s industry, as well as introduce students in technical higher education to up-to-date knowledge within their field. A facility providing a hands-on approach without the risk of interference with real-life manufacturing processes is an essential part of the latter, and, if built and used properly, gives students the motivation and problem-awareness to a degree the combination of theoretical education and “isolated” laboratory exercises would not provide (nor does the inclusion of students in targeted projects give the broad perspective of a project-independent learning and experimenting facility of a “makerspace” character). All of the above motivating factors were taken into consideration in the design and construction of the “Smart Factory” facility at MTA SZTAKI. While some of the educational aspects of the facility are shared with those of a typical learning factory, the “Smart Factory” at SZTAKI is also putting emphasis on a number of further aspects:

• The “Smart Factory” also serves as an experimenting platform for research conducted in the industry, with the future possibility of including the equipment as a test bed in upcoming targeted projects, or offering it as a resource for external users by contract (moving, by the latter, towards a more open “makerspace”).

• The scale of the “Smart Factory”, i.e., a complete set of manufacturing and logistics processes compressed to the size of a single room, allows one-time visitors or the general public to gain an instant impression and thus easily comprehend concise explanations of otherwise complex and diversified fields of science and technology. Therefore, the “Smart Factory” is also playing a role in raising public awareness and improving acceptance of new paradigms with the general public.

• As opposed to the majority of learning factories providing targeted courses with a readily elaborated educational background, the “Smart Factory” is being built up and undergoes constant improvement with the inclusion of students in an individualized, project-based approach. Here, certain knowledge areas and abilities of students (understanding engineering concepts, tackling complexity, balancing contradicting preferences, adaptation to existing technical and social conditions, independent research and technical problem solving) are developed and tested in relation to specific problems whose solutions may remain in long-term use in the facility. Also, the open opportunities of the equipment are expected to encourage students in proposing new development by their own initiative.

2 THE “SMART FACTORY” IN DETAIL

2.1 PRODUCTION SCENARIO AND FOCAL ASPECTS

The “Smart Factory” depicts a complex production facility served with workpieces from a warehouse and manually operated material dispensing/removal points. Workpieces entering the production processes undergo a prescribed series of operations before they are tested and either declared ready for delivery, or discarded as faulty products. In the current configuration, four, structurally identical, workcells are installed to carry out the operations. In the core scenario of the facility, workcells can take part in a bidding process for assignments, and compete for production resources that can be delivered in place for the desired operations.

Intra-logistics, i.e., the transfer of workpieces and movable resources, relies on several components that may be used with a certain degree of interchangeability: (1) a conveyor system connects all workcells, the warehouse and manual access points, (2) two mobile robots can directly transfer workpieces between two specified access or storage points,
and (3) two manipulators can move workpieces between dedicated access points and places of manual material handling (symbolic for, e.g., human rework of faulty parts).

In the “Smart Factory”, much emphasis is laid on process transparency and possible coupling with virtual (possibly remote) subsystems to form a much larger production system, a part of which then operates in physical reality. To this end, each workpiece is assigned a unique identity and can also physically carry information related to the individual product. Moreover, infrastructure is provided for individual online access of all entities (workcells, logistics resources and additional sensors), thereby implementing a key principle of Cyber-Physical Systems. Major components also exhibit a degree of autonomy, allowing an agent-based approach.

External connectivity, including customers, and advanced interaction of automated resources and human operators are further key aspects of the “Smart Factory”, and will be served by high-level graphical interfaces and sophisticated visual and haptic human–machine interfaces on the level of individual agents or agent groups.

The physical layout of the facility allows unplanned changes and disturbances to be introduced at will in many different ways (both via physical intervention as well as data manipulation), so that the robustness and fault tolerance of processes and components can be tested in more diverse ways than in simulation alone. The selection of system components with various interfaces also allows the de-facto evolution of industrial facilities to be depicted where subsystems with different technological legacy must communicate and reliably operate side-by side in the same complex production environment.

2.2 CORE FACILITY COMPONENTS

The core mechanical and control components of the production functionalities in the “Smart Factory” are comprised of FESTO Didactic modules (see also Figure 1). Built of FESTO MPS (Modular Production System) elements (FESTO, 2012; FESTO, 2007a), each of the four identical production cells contains:

- A six-position turntable driven by a stepper motor,
- A pneumatic 2-DOF manipulator for transferring the workpieces to/from the conveyor (serving position 1 of the turntable),
- A pneumatic stamp to test whether the workpiece has been pre-drilled (position 2),
- An electromagnetic stamp marking the workpiece with a given pattern (position 3),
- A slot reserved for a human-operated feedback button to confirm a freely configurable manual operation (position 4),
- A drilling machine (position 5), and
- An electromagnetically actuated flap that can divert the workpiece onto a slide with limited storage capacity (position 6).

Each of the production cells is controlled by a dedicated FESTO PLC that can be accessed via local network and has a number of freely configurable I/O channels to communicate with auxiliary equipment.

2.3 LOGISTICS AND MATERIAL HANDLING

While being custom-designed, the warehouse also relies on FESTO components, such as one more PLC and various pneumatic and electric actuators. The warehouse comprises racks where plastic pallets can be placed on pre-defined locations (Figure 2). Each pallet has four circular recesses for cylindrical workpieces measuring 26 mm in height and 38 mm in diameter (these are resembling the workpieces commonly used with FESTO Didactic components but are custom-designed two-piece urethane castings to meet dimensional and identification requirements specific to the “Smart Factory”). The pallets themselves are not designed to leave the warehouse—instead, the pallet is moved
to a specific loading/unloading location where a 2-DOF manipulator transfers the workpieces to/from the conveyor system. Currently, further functional enhancement of the warehouse is in preparation under involvement of students. Components of the conveyor system are of the FlexLink X45 family (FlexLink, 2015). The facility is served by a closed circle of four conveyor sections, each driven by its own FlexLink X45 drive unit. The conveyor section containing the access point for the robot manipulators is also equipped with a FlexLink X45 stop unit. All X45 are now operating in stand-alone mode, but their addressing over CAN bus is planned for the near future to enable more versatile control and coupling with other system components. In addition to the FlexLink modules, bypass units are currently in the process of installation to improve material handling reserve and workpiece throughput at the external access points and at the workcells. Design and implementation of the bypass modules are an in-house development: the units have a 3D-printed body and diverting flap, and are actuated by an Arduino-driven stepper motor.

Figure 1: General view of the Smart Factory facility with the production cells (left), floorspace accessible by mobile robots (gray area in the middle), and the humanoid manipulators (top right).

Figure 2: View of the warehouse, with the pallet lifter in its home position at the bottom right of the picture

Figure 3: Access point with intermediate storage rack (left), and stop unit mounted in the conveyor path. One of the UR5 robots is about to insert a workpiece into the material stream.

Figure 4: PLC and microcontroller board assigned to one of the production cells.
The facility is also equipped with several local storage racks for 6 workpieces each. Four of these are located adjacent to the workcells (and are partly accessible by the pneumatic manipulator of the corresponding production cell), while a fifth is installed at the robot manipulator access point. Workpieces can be moved between these storage locations by means of two Robotino mobile robots (FESTO, 2007b), each equipped with three omnidirectional wheels, one control unit accessible via wireless network, a camera and a number of optical and inductive sensors facilitating alignment with the pre-defined material handling points. Each mobile robot can move one workpiece at a time.

Among the most recent additions to the facility are two Universal Robots UR5 6-DOF manipulators (Universal Robots, 2014), each equipped with a Robotiq model 85 adaptive two-finger gripper, and a 6-axis force/torque sensor. The conveyor path is within the workspace of both robots, while one of them also has access to one of the aforementioned intermediate storage racks and the access point marked by the conveyor-mounted stop unit (Figure 3).

2.4 SENSING AND HUMAN–MACHINE INTERFACES

In addition to the optical and electro-mechanical sensors used locally by the system components, the “Smart Factory” also relies on a number of sensors to ensure outward process transparency and interaction with human personnel. Tracking and unambiguous identification of individual workpieces relies on NFC tags (specifically, Mifare Classic 1K) embedded in the workpiece castings. In addition to a unique identifier, the tags also accommodate 752 bytes of additional memory that can convey product data. The use of Mifare tags on a commercial scale has two advantages in the context of the facility: (1) costs of tags and associated transceiver equipment are a fraction of that of industrial-grade alternatives, and (2) compatibility with numerous smart phones facilitates the development of product data access and intervention applications, also for possible use in presentations open to the general public where the visitors themselves can install certain access applications on their own smart phones and inspect product data by themselves. In the current configuration being installed, NFC transceivers are connected to Arduino-like microcontroller boards which will also control bypass units associated with some of the readers. Each workcell will have its own microcontroller board accessing 2 (optionally 3) NFC readers and controlling the bypass unit of the cell. In addition, two more boards will be installed at the warehouse, and at the robot manipulator access point, respectively.

Due to its compact size and clear arrangement, most of the facility area can be observed by a single ceiling-mounted wide-angle IP camera. This will serve the purpose of global surveillance of the state of facility components and occupied workpiece locations via image processing, and can also form partial input to telepresence solutions with remote locations latching into the processes of the “Smart Factory”.

While the force and torque sensors of the UR5 robots do support human–machine interaction during physical contact at workpiece handover, it is also important to be aware of humans and possible obstacles elsewhere in the space of the facility. To this end, two Kinect devices were recently installed. The two Kinect units observe the same area of the facility (primarily, the space immediately surrounding the UR5 robots) from two different viewpoints, and their point cloud data can be merged on demand. Kinect devices are supplied with powerful processing and recognition tools that allow the matching of assumed skeletal models to point cloud features, as well as recognition of basic gestures. These are planned to be deployed in future experiments and solutions for human–machine interaction, including scenarios where robots and human operators perform shared manipulation tasks.

A specific class of interaction is the provision of personnel with relevant information, primarily via visual interfaces. While this is, nowadays, typically conveyed via a screen of limited size and fixed location, the seamless merging of large visual interfaces and work surfaces has already been proposed as a means of suggestive and efficient feedback to the human personnel. To this end, a ceiling-mounted projector has been installed which can project visual content onto the desk surface shared by the two robot manipulators and a human operator.
2.5 CONNECTIVITY AND COMMUNICATION

The connectivity architecture of system components is largely determined by two factors: (1) available communication channels of the individual components (LAN, WLAN, CAN, SPI, or simple I/O) impose technical constraints on direct connectivity, necessitating the addition of interfacing units as needed, and (2) direct connection of components should preferably be laid out keeping reliability and isolation of possible communication disturbances in mind.

As mentioned before, the PLCs assigned to the workcells and the warehouse are connected via LAN, and are thus easily accessible by a host computer running high-level execution control. NFC readers, additional sensors and bypass units are connected to microcontroller boards that accommodate an on-board CAN interface (Figure 4). It is, therefore, easy to connect them with a CAN bus which will also be accessed by a CAN-card-equipped Raspberry Pi that has a LAN connection with the high-level host. While it appears to be less than optimal to serve the workcells via two separate communication channels, one must also keep in mind that the microcontroller boards are to be one of the main areas for student experiments which are more likely to introduce faults that need to be safely contained to limit their effect on the entire system. The clean separation of subsystems is also the reason for the pending installation of a second CAN bus dedicated to accessing the X45 modules of the conveyor system.

Connection to further major components is typically solved with LAN access—this applies to the high-level host, the manipulator controllers, and the ceiling camera. The two mobile robots are, as mentioned before, accessed via WLAN over a dedicated wireless router. High-level access to external clients will be provided via web interfaces.

Figure 5 shows the overall architecture of the “Smart Factory” facility in three different perspectives. To the left, the hierarchy of main hardware components is shown, with an emphasis on connectivity (note that this is merely a highly simplified excerpt of all connections and components, omitting several parts that currently undergo final installation). In the middle, the functional components are shown, centered around an agent framework, while the far right lists the main software components deployed at the corresponding hierarchical levels.

Figure 5: Architectural overview of the Smart Factory plant.

3 CONCLUSION AND OUTLOOK

The paper presented the design motivation, context of envisaged use, composition and current state of implementation of the “Smart Factory” facility being built up at the Research Laboratory on Engineering and Management Intelligence of MTA SZTAKI. The facility serves as a test bed for research and development, as a versatile demonstration tool for both industrial audience and the general public, as well as a project-based learning and experimenting environment...
for students in technical higher education. Currently, the facility is still in the phase of construction as the installation and the functional integration certain main components is pending—nevertheless, the system already exhibits several architectural characteristics that are of relevance to today’s intense research behind the concepts of Industry 4.0 and Cyber-Physical Systems. The most important system characteristics in this context are (1) a high degree of real-time process transparency due to the trackability of individual workpieces and rich access to the state and information handled by system components, (2) modular control structures enabling the autonomous operation of sub-systems or components, and (3) multi-directional interaction of components, human operators and external users.

Aside from completing the installation and functional integration of all components, higher-level functionalities are planned to be implemented in the near future. These will include external connectivity, allowing, among other things, the coupling of the facility with other higher-level entities (e.g., customers, members of a simulated production network, or virtual production facilities), thereby depicting another important aspect of Industry 4.0 that is often emphasized to deserve closer attention in industrial development.

Regarding its role in education, the “Smart Factory” is receiving growing attention in the immediate educational surroundings of the host institute, and has been a key to the success of several ambitious student projects. While thereby being somewhat off the most numerous classes of learning factories, the facility serves as a platform for project-oriented work (and consequent development of competencies) as opposed to pre-assembled courses, and has the potential of evolving into a “makerspace” due to its openness to independent initiatives. This, however, does not preclude the possibility of hosting courses or lab exercises once a stable set of configurable functionalities and resources is established.

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5 LIST OF REFERENCES


TRAINING PLATFORM OF THE GREEN FACTORY BAVARIA IN AUGSBURG

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Abstract
Global research consumption shall decrease due to limited resource availability and negative environmental side-effects. One way to do that is to increase the resource efficiency in manufacturing. This is the aim of the Green Factory Bavaria in Augsburg, which serves as a research-, demonstration- and training platform. In this paper the project will be explained with emphasis on the training aspect.

1 INTRODUCTION

Global resource consumption grew by almost 100 % over the past 30 years (Dittrich 2014). The current consumption level is not sustainable and will have to decrease eventually due to limited resource reserves. A more important factor is that the resource consumption is linked to a number of environmental pollutions such as anthropogenic climate change (Qin, Plattner, Tignor, Allen, Boschung, Naue, Xia, Bex, Midgley 2014), causing high macroeconomic costs (Stern 2006), so that an early reduction seems desirable. Apart from these macroeconomic considerations there are also microeconomic reasons for decreasing the resource consumption, most notably the increased price of many resources and the increased end customer awareness for sustainable products (Abele & Reinhart 2011). The latter fact is demonstrated by a survey from the German VDI (VDI 2011), in which 51 % of the interviewed manufacturers state that their customers increasingly demand a more resource efficient production, regardless of the cost aspects. Concluding, it is important to decrease the global resource consumption.

Decreasing the resource consumption, i.e. the material and energy consumption, is even more important in Bavaria since an energy shortage is feared. This is because Bavaria is going to shut down its nuclear power plants until 2022 (Bundesgesetzblatt 2011), which contributed 48 % to the Bavarian electric energy generation in 2013 (Appold 2015) and because Bavaria strives to put into action 200,000 electric vehicles until 2020 (Schneider 2014) increasing the state’s energy demand.

One way to decrease the resource consumption is to increase the resource efficiency in production. This is the goal of the Green Factory Bavaria project initiated by the Bavarian Government [Unterberger & Frank 2015, Kreitlein 2015]. The members of the Green Factory Bavaria are two Fraunhofer project groups, the Fraunhofer IWU project group Resource efficient Mechatronic Processing Machines in Augsburg and the Fraunhofer IPA project group Process Innovation in Bayreuth, as well as a group of eight Bavarian universities. As part of the project two real factory environments will be created in Augsburg and Bayreuth. They differ in terms of the production processes they focus on.

2 GREEN FACTORY BAVARIA IN AUGSBURG

The platform in Augsburg will serve as a combined research, demonstration and training platform, where research findings will be demonstrated to the public and taught to industrial customers and students through seminars and courses. It will focus on increasing the resource efficiency of the manufacturing processes instead of supporting HVAC processes or the factory building. While HVAC processes often represent a large share of the resource consumption
of a factory and may be more easily changeable, their efficiency has already significantly increased over the last decade [Dickerhoff 2015] and further similar disruptive increase can not be expected. In contrast to that the resource efficiency of production machinery has so far only been tackled by a few manufacturers. Hence, we anticipate a larger improvement potential in this area.

A manufacturing process usually consists of a forming, a post-processing and a packaging step. This holds true for the process chain at the Green Factory Bavaria in Augsburg (see Fig. 1). Starting with the forming selective laser melting step, the resulting parts undergo chipping processes to improve the surface quality and are cleaned from residual metal powder particles and cooling lubricants. Finally, they are packaged in a plastic foil, which is relevant for e. g. additively manufactured medical implants. Additive manufacturing was chosen as a major process step, since the technology itself represents a great opportunity to increase the resource efficiency and since it has thus far been little researched with the goal of optimizing its resource efficiency.

![Figure 1: Individual process steps of the Green Factory Bavaria in Augsburg](image)

Based on this process chain several ideas for improving its resource efficiency are investigated. For example, concerning the additive manufacturing step the effect of powder quality on built part quality is thoroughly analyzed, in order to be able to recycle non-solidified powder more often. For the cleaning step the applicability of different biologic cleaning agents is examined, which transform oil based cooling agents rather than dissolve them, thus not needing replenishments. Concerning the packaging step, one goal is to avoid unnecessary large plastic packages by increasing the format flexibility of thermoforming machines.

### 3 TRAINING PLATFORM

The aim of the training platform is to impart those competences to industrial customers and students which are necessary for increasing the resource efficiency in manufacturing. This comprises the knowledge about typical exemplary efficiency measures but more importantly methodical knowledge of how to identify and assess new resource efficiency measures. Hence, in trainings the following learning goals shall be reached:
• Participants can enumerate several reasons for increasing the resource efficiency in production companies.
• Participants can systematically scan a factory for possible energy efficiency measures.
• Therefore, participants have the skill to choose suitable measurement instruments and to operate relevant ones.
• Participants can assess the identified possible efficiency measures in terms of economic and ecologic indicators while considering the whole life cycle of technology alternatives.
• Participants can list several typical energy efficiency measures employed in manufacturing.

Based on these learning goals a one week training for students has been developed. The first two days focus on conveying the methodic procedural knowledge through theory and simplified examples. After that the students apply their knowledge to the individual process steps of the Green Factory in Augsburg.

Compared to students, industrial customers have much more heterogeneous prior knowledges and demands on the training. Hence, for this group a modular training platform was designed, of which individual training sessions can be composed. In order to offer a large variety of training modules, a cooperation between the training platform of the Green Factory Bavaria in Augsburg and the Green Factory Bavaria in Bayreuth is planned (see Fig. 2). The training modules range from methodic trainings such as life cycle assessment over cross-section technology topics such as pressurized air or lighting to process specific trainings, e.g. in the area of additive manufacturing or carbon fibre reinforced plastic manufacturing. Trainings are scheduled to start in 2016.

4 SUMMARY

In this paper the concept of the Green Factory Bavaria in Augsburg was described including its new training platform for industrial customers and students. The goal of the trainings is to impart those competences to the participants, which are deemed necessary for increasing the resource efficiency of manufacturing process. Training will begin in 2016 as a one week internship for students and as a modular platform for industrial customers.
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LEAN LEARNING FACTORY: LESSONS LEARNT

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Abstract
Learning factories, in various forms, have been in use for some time now and the related knowledge base is constantly growing. As the concept becomes more widely adopted it is important to record lessons learnt so that organisations that are in the process of building or adopting this teaching methodology can avoid mistakes already made and utilise the findings of existing learning factories.

1 INTRODUCTION
Teaching assembly related lean and industrial engineering tools and techniques effectively requires some form of practical training in an industrial environment as this enhances the learning experience (Abele & Eichhorn, 2008). This is particularly true in a university where a significant proportion of the students are from rural backgrounds with no understanding of large scale assembly operations. Introducing this type of training as early as possible has obvious benefits for students but is often difficult to facilitate in a real industrial environment. Wagner et al. (Wagner, AlGedawy ElMaraghy & Muller, 2012) also point out that this type of learning environment is ideal for transferring research outcomes to industry.

To address this need, learning factories have been developed and built in a number of universities around the world including a Lean Learning factory at the Nelson Mandela Metropolitan University (NMMU), Department of Industrial Engineering, situated in the city of Port Elizabeth, South Africa. The facility is referred to as the simulated working environment for assembly training laboratory or the SWEAT Lab and was commissioned early in 2014 in relative isolation as the department was unaware of similar projects that were also underway around the world. Challenges were (and still are) encountered as the facility’s utilisation increases in terms of training frequency as well as complexity and it is these challenges that are presented in this paper. The next section contains an overview of the SWEAT Lab and is followed by discussion around the lessons learnt.

2 OVERVIEW OF THE SWEAT LAB
Funding was obtained for a multi-station moving assembly line, materials and the space to house the facility. The final design of the assembly line is shown in figure 1. Up to 23 operators/students can be accommodated in the SWEAT Lab, performing various functions that include assembly, material handling, quality control and dis-assembly. A de-brief area incorporating lockers and benches is situated alongside the material storage area. In the de-brief area teams discuss and analyse performance and problems that they experienced during production runs with a view to developing improvements.
The second step in the project was to design the jobs for each student/operator and to develop a structure for the lean learning exercises. At the outset, four one-hour production sessions were conducted with student teams taking responsibility for developing improvements between each session, equating to three improvement opportunity sessions. Work content for each student/operator was purposefully unbalanced and training/instruction were vague; no targets are officially communicated and the emphasis is on volume of production. Material layout is poor and material handlers travel circuitous routes to collect parts for the assembly line. Tools are also placed in random positions around the assembly operation.

After a fairly chaotic and frenzied one-hour session teams are withdrawn from the line and gathered in the de-brief area where production statistics such as units produced and number of rejects are revealed. Time for discussion, analysis and improvement is allowed before the next session (incorporating student suggestions) commences. This process is repeated over three sessions and the performance levels of each session recorded. In this way the important lean practices (listed in the previous section) are used to develop ongoing improvements (van der Merwe, 2015). Examples of specific lean tools used at each stage are listed in table 1. The scenario that creates the need for the tool is also indicated in this table; although teams are free to select tools as and when they decide the tool is needed.

**Table 1: Lean tool/practice scenario and application**

<table>
<thead>
<tr>
<th>Improvement session</th>
<th>Lean tool/practice</th>
<th>Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>One</td>
<td>5S</td>
<td>Work tools are scattered around the line in random places. Battery operated tools are deliberately provided with very little charge.</td>
</tr>
<tr>
<td></td>
<td>Visual management</td>
<td>Material handling trolleys randomly placed and bins have no labels. Good parts are not separated and identified.</td>
</tr>
<tr>
<td></td>
<td>Single piece flow</td>
<td>Batches of three products are released into production simultaneously.</td>
</tr>
<tr>
<td>Two</td>
<td>Takt time</td>
<td>Customer demand figures are introduced.</td>
</tr>
<tr>
<td></td>
<td>Line balancing</td>
<td>Unbalanced operator workloads.</td>
</tr>
<tr>
<td></td>
<td>Set up reduction</td>
<td>Long and complicated changeovers.</td>
</tr>
<tr>
<td>Three</td>
<td>Kanban</td>
<td>Oversupply to the line.</td>
</tr>
<tr>
<td></td>
<td>Process mapping</td>
<td>Inefficient processes and procedures</td>
</tr>
<tr>
<td></td>
<td>Teamwork and versatility</td>
<td>Key operators removed from the line due to “illness”.</td>
</tr>
</tbody>
</table>

Note: the seven wastes and continuous improvement are addressed in each session.
The exercises described above are typical of the current practical training sessions and are constantly being developed and adapted to improve the learning experienced by the students.

3 LESSONS LEARNT

A number of lessons have been learnt over the last two years that are relevant for consideration by other institutions or organisations that are planning to develop their own learning factory. These lessons have been placed into the following categories.

a) Complexity and objectives

The original concept for the NMMU learning factory was based on the General Motors simulated working environment model which is a relatively simple non-automated assembly line that is used to train all GM employees in the basics of the GM global manufacturing system. However, being engineers the NMMU team designed the learning factory to deal with complex manufacturing scenarios and included sophisticated manufacturing software for production monitoring and control. The problem associated with these systems is that more basic training in lean assembly is inhibited by system constraints and information feedback systems that require in-depth knowledge of production monitoring systems. Cachay and Abele (2012) support the need for careful consideration of competencies that are to be assessed.

Lesson learnt: match the degree of system complexity to the learning objectives.

b) Product and process design

Careful consideration must be given to the design and material of the product that is assembled. The current product that is assembled in the learning factory requires a high degree of manual dexterity which is not a skill that the majority of first year students possess. An imbalance in performance results that is difficult to address whilst simultaneously teaching lean tools and techniques. Due to the relatively high cost of the product components it is not always possible to introduce an entirely new product.

Lesson learnt: If the primary intention is to teach undergraduate students then the product and process design must take this into account.

c) Flexibility

The main component of the learning factory is a fixed roller conveyor line that is driven by two electric motors. Arranged in a rectangular shape the conveyor system has a short section that lifts to allow operator entry. A minor inconvenience here is that people cannot enter and exit the line when it is in operation but more importantly the fixed nature of the line (continuous and bolted to the floor) negates system design exercises by the students as the layout is not flexible. Ergonomic studies and experimentation are also difficult when the assembly system is fixed.

Lesson learnt: Modular design of the assembly line would allow for more flexibility when conducting process design exercises and allows for a greater range of exercises.

d) Continuity

Closely linked to complexity and objectives is the concern surrounding continuity of learning factory staffing. As with many other university learning factories the NMMU facility is run by senior students (overseen by a staff member) on yearly contracts who are doing research – these high level students leave as soon as their research projects or studies are complete which means that the new incumbent must start from the beginning again.

Lesson learnt: Give serious consideration to appointing a full-time staff member to run the learning – allowing him/her to continually build and refine each learning exercise.
Building blocks

Initial exercises were designed to incorporate too many principles simultaneously. These exercises were designed to be conducted over a minimum period of six hours. The problem with this approach is that the basics are not always properly embedded before moving on to more complex principles. Junior students at this institution display vastly differing skill levels during the first year of studies. A hierarchy of learning should be developed that culminates in self-organising processes that are performance-oriented as proposed by Cachay et al. (Cachay, Wennermer, Abele and Tenberg 2012).

Lesson learnt: start the learning activities with shorter (two-hour) basic exercises from safety induction level upwards.

4 CONCLUSION

The learning factory concept has changed the way lean and assembly teaching is carried out and the potential for increased utilisation of this concept is significant. It would not be unreasonable to assume that the number of universities that adopt the idea will grow exponentially over the next decade. Avoiding mistakes and learning from the experiences of others is an essential part of the learning factory journey and it is for this reason that sharing lessons learnt and new ideas is important. Limited discussions with other universities that have similar facilities has already given us new ideas and projects for the future.

5 LIST OF REFERENCES


Learning Factories for engineering and business education gain popularity world-wide, in both university education and vocational training. Ten leading institutes have allied in the Network of Innovative Learning Factories, a project funded by the German Academic Exchange Service, to develop further the idea of Learning Factories jointly, to learn from each other about best practices in Learning Factory design and operation and to boost the exchange of researchers and students between single facilities.

When first Learning Factories were implemented in Europe in the mid 2000s, their primary purpose was to innovate university education and vocational training in the field of industrial production engineering and management – from ex-cathedra teaching to action-oriented training that delivers holistic occupational competence in the most important methods around value-creation. While this might still be every Learning Factory’s focus today, its contentual emphasis is developing further.

This second edition of The Learning Factory proves that Learning Factory operators are mindful of socio-technological progresses in their respective environments: The virtualization of product and factory planning, the digitization of the actual production processes through a bold integration of ICT (commonly referred to as Industrie 4.0) and a deliberate consideration of resource efficiency are exemplary driving forces of new competency requirements for future engineers. Learning Factories are at the forefront of delivering these competencies for the benefit of society and economy.

At the same time, it becomes evident in this year’s edition that the Learning Factory concept of a joint hands-on education and applied research environment is no longer a predominately European phenomenon, but already an export model also to industrializing economies - such as South Africa.