9th Conference on Learning Factories
March 26th-28th 2019
Technische Universität Braunschweig

Paper Sessions
Preliminary Schedule
Session I – Learning in Industry 4.0 and cyber-physical production systems (CPPS) #1
27.03.2019 – 11.00-12.30 – Die Lernfabrik – Session Room A
Session Chair: Prof. Joachim Metternich

Interactive Learning of Assembly Processes using Digital Assistance
Hendrik Oestreich¹, Torben Töniges², Michael Wojtynek³, Sebastian Wrede³
¹Research Institute for Cognition and Robotics (CoR-Lab), Bielefeld University, Universitätsstr. 25, 33615 Bielefeld, Germany

Due to an increasing demand for individualized products and the resulting high variability in manufacturing processes, flexibility and cognitive skills of human workers are highly important for manual assembly processes. Nowadays, novice workers are often trained by colleagues or foremen in addition to and alongside their main work. Since time is usually scarce and the procedure can be highly variable, one solution for the companies can be the introduction of digital assistance systems. Hence, the focus of this contribution is the initial learning procedure of the assembly of a new and complex product. Therefore, a user study was conducted in close cooperation with an industrial partner to compare the traditional way of training to the self-paced learning with a digital assistance system. During the execution of the user study, objective data was recorded to allow precise measurements of the individual learning progress. Furthermore, the subjective learning experience was assessed using a customized questionnaire and a standardized task load metric. The evaluation of the study results suggests that learning autonomously with a digital assistance system leads to similar performance curves as learning the process through a personal explanation.

A Practical Approach of Teaching Digitalization and Safety Strategies in Cyber-Physical Production Systems
Titanilla Komenda¹,², Gerhard Reisinger¹,² and Wilfried Sihn¹,²
¹Fraunhofer Austria Research GmbH, Theresianumgasse 7, 1040 Vienna, Austria
²Technische Universität Wien, Institute of Management Sciences, Theresianumgasse 27, 1040 Vienna, Austria

Digitalization strategies in cyber-physical production systems (CPPS) are one of the key factors of Industry 4.0. The topic not only addresses data preparation, real-time data processing, big data analytics, visualization and machine interface design but also cyber security and safety. Especially, unauthorized access to protected (personal or enterprise) data or unauthorized control of production facilities imply risks when it comes to digitalization. Because of the increased complexity of state-of-the-art technologies, educational institutions need to provide practice-oriented teaching methods in learning factories to help engineers of today understand the impact of those developments. In the light of this fact, this paper presents a practical approach of teaching digitalization strategies in CPPS. Planning, implementing and impacts of digitalization strategies are taught on a use-case with human-robot-collaboration. The objective of the use-case is to realize a real-time obstacle avoidance approach for a collaborative application based on a local positioning system. Here, students not only learn how to model the kinematics of a robot and program a robot but also how to design machine interfaces for real-time data transfer and processing as well as impacts of digitalization on safety and security. The implementation of the use-case is part of the TU Wien teaching portfolio and thus part of its learning factory, where students and apprentices have the possibility to experiment and gain experiences by deliberate error simulations.

Implementation of a cyber-physical cooling storage station in a learning factory
Marcus Vogt¹, Benjamin Uhlig¹, Kuldip Singh Sangwan², Christoph Herrmann³, Sebastian Thiede³
¹Technische Universität Braunschweig, Institute of Machine Tools and Production Technology, Sustainable Manufacturing and Life-Cycle Engineering, Langer Kamp 39 b, Braunschweig, 38106, Germany
²Birla Institute of Technology and Science, Pilani, Pilani Campus, Vidya Vihar, Pilani 333031, Rajasthan, India

Learning factories are established means for learning production and process-engineering relevant topics and improving holistic system understanding. Learning factories integrate real-world applications into small-scaled factories to teach students, employees or researchers. Connecting the physical world with virtual (cyber) models to develop cyber-physical systems has become attractive due to low cost, high performance IT infrastructure. However, learning factories and cyber-physical systems have been rarely combined. In this paper, a cyber-physical cooling storage station is presented, which is integrated into an existing learning factory and its potential for engineering education is analysed. In addition, an innovative
visualisation enables user interaction for learners. This system allows learners to experience the interaction of thermodynamic processes, industrial sensors and industrial automation to deepen their knowledge in laboratory exercises.

---

**Human Robot Interaction – learning how to integrate collaborative robots into manual assembly lines**

Henning Oberes, Christopher Prinz, Paul Glogowski, Kai Lemmerz, Bernd Kuhlenkötter

*Ruhr-Universität Bochum, Chair of Production Systems, Universitätsstraße 150, 44801 Bochum, Germany*

Human-Robot Collaboration (HRC) is one of the main challenges for companies today. Despite the trend on collaborative robots, use cases within manufacturing systems seem to be still rare. Although collaborative robots are promised to be one of the crucial innovations for ergonomically assistance for blue collar workers, the integration process into the production process and the preoccupation of workers against robot assistance alike, can be assumed as biggest challenges for companies. One of the reason might be the missing methodology and simulation tools for quick analysis of workplaces, in order to detect possible workloads for robots. The given article presents a developed learning factory seminar for students as well as industrial participants on how to integrate collaborative robots into manual assembly lines. This approach focuses on the problem based learning structure of the seminar and on the essential methods and developed concepts which are necessary to analyze workplaces, simulate robot integration with the possibility of analyzing the distributed workload between the worker and the robot. Tools as a “quick check” analysis for HRC and the simulation software Editor of manual work activities (ema) will be integrated during this concept. Besides the technological implementation and the different organization of work by implementing HRC in a production process, the participants will also discuss the asects and changes for the employees. This will cover the T-O-E (technology-organization-employee) approach [1] and will help to design an implementation project for HRC.

---

**Development of an education program for digital manufacturing system engineers based on ‘Digital Triplet’ concept**

Yasushi Umeda, Jun Otai, Fumio Kojima, Masahiro Saito, Hiroki Matsuzawa, Takuju Sukenkawa, Akhide Takeuchi, Kazuya Makida, Shouhei Shirafuji

*Department of Precision Engineering, School of Engineering, The University of Tokyo, Hongo 7-3-1, Bunkyō, Tokyo 113-8656, Japan*

b RACE (Research into Artifact, Center for Engineering), The University of Tokyo, Kashiwano 9-1-5, Kashiwa, Chiba 277-8568, Japan

c Production Promotion Center, Denso Co., Showacho 1-1, Kariya, Aichi 448-8661, Japan

In the Industry 4.0 era, cyber-physical manufacturing systems (CPPS) has started to change activities of manufacturing system engineers into CPS based ones. In typical Japanese factories, manufacturing system engineers are always stationed at the shop floor and continuously improve manufacturing systems with workers. For supporting such engineers’ activities, we are developing the concept of ‘Digital Triplet’ as an extension of Digital Twin. Digital Triplet consists of intelligent activity world in addition to the cyber world and the physical world and supports manufacturing system engineers in developing engineering processes with the cyber and physical worlds. Based on this, we are developing an education program. In this paper, we first describe the concept of Digital Triplet. Next, after explaining the overview of the education program, we introduce a course in which trainees (mainly novice engineers) execute ‘Kaizen’ with a prototype CPS system of a learning factory.

---

**Connectivity as a prior challenge in establishing CPPS on basis of heterogeneous IT-software environments**

Stefan Trabesinger, Rudolf Pichler, Daniel Schall, Richard Grferer

1Institute of Production Engineering, Graz University of Technology, Inffeldgasse 25/F, Graz 8010, Austria

2Siemens AG Austria, Siemensstraße 90, 1210 Vienna, Austria

3T-Systems Austria GesmbH, Rennweg 97-99, 1030 Vienna, Austria

More and more elements in a modern production system are becoming smart devices and it is reasonable to integrate them into a Cyber Physical Production System (CPPS) in a consistent manner. There is the broad goal of many industrial players to open the rich potential of the Industrial Internet of Things (IIoT), which has to be fast, secure and adaptive. The growing number of “things” in a production system requires satisfying connectivity solutions that are different to an easy coming
“Peer-to-Peer architecture (P2P)”. The approach followed at the smartfactory@tugraz – the Learning Factory of Graz University of Technology in Austria – to achieve such an integration is to deploy an Enterprise Service Bus (ESB), which is at the core of Service Oriented Architecture (SOA). The goal is to integrate three main software applications including the Product Lifecycle Management (PLM), the Enterprise Resource Planning (ERP) and the Management Execution System (MES). The additional challenge in this project is that these mentioned main applications are all provided by different suppliers. The selected SOA approach provides the basis for a scalable and extensible solution via Connectivity Modules and standardized interfaces. The smartfactory@tugraz validates this SOA approach by applying it to a real and fully operational manufacturing line. The smartfactory@tugraz is not only a learning factory but rather an open ecosystem by offering both students and researchers as well as industrial partners the ability to perform research on this subject. It is thus the ideal place to study the challenges and to understand the benefits of pushing a CPPS to a mature level in terms of connectivity in a manufacturing context.
Session II – Learning Factory Concepts #1
27.03.2019 – 11.00-12.30 – Die Lernfabrik – Session Room B
Session Chair: Prof. Dr. Dimitris Mourtzis

The virtual FMS – an engineering education environment
Hasse Nylund\textsuperscript{a}, Veikko Valjus\textsuperscript{b}, Ville Toivonen\textsuperscript{a}, Minna Lanz\textsuperscript{a}, Harri Nieminen\textsuperscript{b}
\textsuperscript{a}Tampere University, Faculty of Engineering and Natural Sciences, P.O. Box 389, FI-33104 Tampere, Finland
\textsuperscript{b}Fastems Oy Ab, Tuotekatu 4, FI-33840 Tampere, Finland

The challenge of education related to large technical systems is to provide enough hands-on experience. Virtual models and visualizations make it easier to explain the behavior of those systems. This paper discusses the development of such a learning environment for engineering education that focuses on planning, operation, and analysis of Flexible Manufacturing Systems (FMS). The aim of the learning environment is to allow the students to achieve the intended learning outcomes mostly with learning by doing. For this purpose, the learning environment is introduced and the individual exercises are described with their teaching and learning activities. This kind of learning by doing in an environment, which is similar to environments in manufacturing companies, enhance the learning results and serve the needs of the industrial companies recruiting the students.

Center of Excellence for Lean Enterprise 4.0
U. Dombrowski\textsuperscript{a}, J. Wullbrandt\textsuperscript{a}, S. Fochler\textsuperscript{a}
\textsuperscript{a}Technische Universität Braunschweig, Institute for Advanced Industrial Management, Langer Kamp 19, 38106 Braunschweig, Germany

Lean Production Systems are state of the art in manufacturing industry. A Lean Enterprise integrates all business units, such as Lean Development, Lean Production and Lean Sales and Service, as well as Lean Administration or Lean Leadership in order to maximize efficiency and effectiveness of value creation on an overall level. Current research suggests that the process orientation as well as the efficient design of value streams within a Lean Enterprise are the necessary foundation for the beneficial implementation of Industrie 4.0. However, changes in the working environment through Industrie 4.0 applications as well as the need to sensitize employees in terms of interdisciplinary thinking, process orientation and interconnected value creation lead equally to changed competency requirements in future world of work. After giving a theoretical presentation on changed competency requirements for the employees of the future, it will be shown how the Institute of Advanced Industrial Management (IFU) at Technical University Braunschweig makes a structured contribution to meet these requirements. The aim is to develop fully integrated practical learning environments to give students as well as employees from industry the opportunity to experience the benefits of integrating all enterprise areas in a holistic Industrie 4.0 approach – the Lean Enterprise 4.0.

Development of Learning Factory at FSRE, University of Mostar
Željko Stojičić, Igor Bošnjak
\textsuperscript{a}University of Mostar, Faculty of Mechanical Engineering, Computing and Electrical Engineering, Matice hrvatske b.b., Mostar, Bosnia and Herzegovina

Dominant trends in manufacturing such as shorter lead times and product life cycles demand quicker transformations in the factory. Employee competencies are the key resource in today’s economy, where the production sector is one of the most important pillars. Companies need to quickly adapt to current challenges at all levels. In the past few years, learning factories as close-to-industry environments for education and research have proven to be an effective concept addressing these challenges. Numerous learning factories for education, training, and research have been established in industry and academia all over Europe and the whole world. This article presents the concept of the learning factory (LF) at the Faculty of Mechanical Engineering, Computing and Electrical Engineering (FSRE). The paper presents different definitions and the basic concept of the learning factory, with emphasis on the information system, curriculum and product in the LF. The following sections present the current state and concept of FSRE LF with respect to infrastructure and equipment, as well as describe the current curriculum offered to industry and students, the LF product and selection process, development and manufacturing.
AD Design Guidelines for Implementing 4.0 Learning Factories
Erwin Rauch\textsuperscript{a}, Florian Morandelli\textsuperscript{b}, Dominik T. Matt\textsuperscript{a,b}
\textsuperscript{a}Industrial Engineering and Automation (IEA), Faculty of Science and Technology, Free University of Bolzano, Universitätsplatz 5, Bolzano, 39100, Italy
\textsuperscript{b}Fraunhofer Italia Research s.c.a.r.l., Via A. Volta 13a, Bolzano, 39100, Italy

Learning Factories (LF) are becoming increasingly popular to teach students, how the methods and concepts learned in theory work in a hands-on and industry-related environment. In recent years, many learning factories have been established and experiments have been carried out in the application of practical learning methods. In most cases, these consist of demonstration lessons as well as the opportunity to design, test and optimize production systems and processes in practice. With the introduction of industry 4.0 (I4.0) also many learning factories have to adapt their education model as well as their offer in order to meet the expectations of students and companies. So far, there are only few works dealing with this topic and providing adequate design guidelines. This paper therefore aims to use a systematic and structured way to develop such design guidelines for I4.0 learning factories. As research method, Axiomatic Design is applied by translating students’ and companies’ needs into functional requirements and then into a set of design parameters/guidelines.

Integration of Active Pharmaceutical Ingredient production into a pharmaceutical Lean Learning Factory
Natalie Petrusch\textsuperscript{a}, Felix Sieckmann\textsuperscript{a}, Jan P. Menn\textsuperscript{b}, Holger Kohl\textsuperscript{b,c}
\textsuperscript{a}Fraunhofer Institute for Production Systems and Design Technology, Pascalstraße 8-9, 10587 Berlin, Germany
\textsuperscript{b}Technische Universität Berlin, Pascalstraße 8-9, 10587 Berlin, Germany

In the context of the implementation of Lean Production Systems, companies have become significantly more aware of the need for employee qualification and motivation. Due to the high share of practice, Learning Factories have proven to be an effective approach to respond to this circumstance. While the focus of Learning Factories has so far mainly been on discrete manufacturing, applications in the pharmaceutical industry are still comparatively rare. Based on this, a Learning Factory, that takes into account the special requirements and needs of the pharmaceutical industry, was developed and implemented in collaboration with a German pharmaceutical company. So far, Lean culture and tools have been trained on formulation and packaging processes. However, the active pharmaceutical ingredient (API) production, which is characterized by a higher level of automation as well as chemical and process engineering procedures, was initially not displayed, as no sufficient demand was assumed. Due to the increasing need for a holistic consideration of the whole value chain, the API production is moving into the focus of Lean improvements. In this context, many established tools need to be adapted. From feedback of over 120 conducted trainings and a series of interviews, it became clear, that for employees from API production, it is difficult to transfer the necessary knowledge to their work environment, leading to resistance in implementing Lean tools. In order to counter this problem, the Learning Factory was expanded by an additional API learning module. This increased the willingness of employees to participate in the trainings and to implement the contents.

A Learning Factory concept for skills enhancement in rail car manufacturing industries
Nkateko Maheso\textsuperscript{a}, Khumbulani Mpofu\textsuperscript{a}, Boitumelo Ramatsete\textsuperscript{a}
\textsuperscript{a}Tshwane University of Technology, Staatsartillierieroad, Pretoria West, Pretoria 0001, South Africa

Rail manufacturing industries plays a key role in various countries by developing cost effective transportation solutions that could be used more efficiently to provide movement of freight and passengers. To date, the sector has experienced an increase in technological investments that are fundamental in driving efficiencies, better managed operations as well as offer passenger-focused-services (PFS) through industry 4.0 initiatives. Despite this wave of innovative technologies, the rail industry is struggling to bring them into full fruition due to a significant skills shortage. While various learning factories have been established both in industry and academia in the last decades, there is a need to interlink the activities within these various learning factories in order to address skill shortages. This paper aims at developing that link which will bridge the gap by establishing a state of the art learning factory (LF) concept that incorporates strategic initiatives such as customised training programmes and hands on experience to benefit graduates from various engineering disciplines in order to be ready for industry. Various concepts were developed and selected using decision matrix processes through the allocation of certain scores and ratings on each criterion as well as of synthesis of this rating using the standard procedures obtained through the
application of Pugh Matrix, in order to select the most optimum LF design concept. In addition, a systematic layout planning (SLP) approach was used to analyse the sequence of operation performed within the proposed LF concept as well as understanding the relationship between the various workstations. The results reveal the chosen concept which the most suitable characteristics in LF design for the rail manufacturing industry. Lastly various projects were proposed in order to determine the performance of student group within the proposed LF concept.
Session III – Mixed Reality and immersive learning environments #1
27.03.2019 – 13.30-14.15 – Die Lernfabrik – Session Room A
Session Chair: Dr. Dimitris Mavrikios

Development of a low cost machine vision based quality control system for a learning factory
Louis Louw*, Marli Droomer*
*Industrial Engineering Department, Stellenbosch University, Joubert Street, Stellenbosch, 7600, South Africa

Learning Factories provide a promising environment for developing the competencies required from a future workforce to apply and integrate technologies associated with digitalised production environments and cyber-physical systems. This paper describes a student project for the development and implementation of a low cost machine vision based quality control system within a Learning Factory. A prototype system was developed using low cost hardware and open source software freely available. The system will be used towards further research and development of more intelligent manufacturing systems within the Learning Factory, based on machine vision. A second benefit was student competency development through self-learning and experimentation. It serves to illustrate how the education as well as research goals of a Learning Factory can be addressed simultaneously through student projects.

Augmented Go & See: An approach for improved bottleneck identification in production lines
Constantin Hofmann*, Tom Staehl*, Samuel Cohen*, Nicole Stricker*, Benjamin Haefner*, Gisela Lanza*
*Karlsruhe Institute of Technology, Kaiserstrasse 12, Karlsruhe, 76131, Germany

Bottlenecks in production lines are often shifting and thus hard to identify. They lead to decreased output, longer throughput times and higher work in progress. Go & See is a well-established Lean practice where managers go to the shop floor to see the problems first hand. Mixed reality is a promising technology to improve transparency in complex production environments. Until recently, mixed reality applications have been very demanding in terms of computing power requiring high performance hardware. This paper presents an approach for real-time KPI visualization using mixed reality for bottleneck identification in production lines relying on the bring-your-own device principle. The developed application uses image recognition to identify work stations and visualizes cycle times and work in progress in augmented reality. With this additional information, it is possible to discern different root causes for bottlenecks, for example systematically higher or varying cycle times due to breakdowns. This solution can be classified according to the acatech industry 4.0 maturity model as a level 3 – transparency – application. It could be shown that the identification of bottlenecks and underlying reasons has been improved compared to standard Go & See.

Outline of an Industry 4.0 Awareness Game
Steffen Tram Mortensen*, Kelvin Koldsø Nygaard* and Ole Madsen*
*Aalborg University, Department of Materials and Production, Fibigerstræde 16, Aalborg East, 9220, Denmark

The introduction of Industry 4.0 brought a demand outside the academic world for understanding the Industry 4.0 principles and how they will influence the industry and education domain. Aalborg University has developed an Industry 4.0 Awareness Game to address the new paradigm and rapidly emerging technologies. The game is based on the Aalborg University learning factory, AAU Smart Production Lab. The game is an introduction to Industry 4.0 where the participants gain knowledge about the driving technologies and new qualifications. The scope of the game is to provide a platform where the participants will produce the right product at the right time. The participants, who are non-experts and may have different educational backgrounds were divided into six roles/departments: Operator, Production Managers, Logistics, Circular Economy, Service Technician, and Game Observer. Role cards, given to each group, at the beginning of the game, stating the responsible areas and the task descriptions. By introducing new Industry 4.0 technologies, by a deck of game cards, continually in the game, e.g., collaborate robots, data mining, analysis tools, and reconfiguring manufacturing systems, the participants gain first-hand experience on how these technologies influence the production but also on the impact of needed qualifications and management of the production. The game cards may introduce disruptions, e.g., errors of process or conveyors, to create awareness of a weakness in the production and how vital adaptability is in the production. The game received favorable reviews from both participants from the industry and the education domain. Through the experience in the AAU Smart
Production lab, the participants gain an understanding of the complexity of a holistic approach. They gain awareness and get inspired on the various ways that different technologies may be integrated and create impact across several traditional functions. As main outcome of this game we highlight the need for an interdisciplinary approach for utilizing Industry 4.0 technologies.
Session IV – Learning Factory Concepts #2
27.03.2019 – 13.30-14.30 – Die Lernfabrik – Session Room B
Session Chair: Prof. Vera Hummel

Learning environment for robotics education and industry-academia collaboration
Minna Lanz, Roel Pieters, Reza Ghabcheloo
Tampere University, Engineering and Natural Sciences (ENS), P.O. Box 589, Tampere, Finland

It is expected that by utilizing digital technologies, advanced robotics and artificial intelligence, the manufacturing base of Europe will become stronger and allow production re-shoring from other trade areas to take place. The European competitiveness is tied to better competences of the workforce and fast implementation of new technologies. This requires new approaches for formal and non-formal education. For this, we propose a new robotics learning concept and collaboration scheme to support both MSc level education, but also non-formal education with industry. The non-formal education example could be a combination of an education package followed by rapid experimenting with a robot system. In order to facilitate the learning process, we have established the Tampere RoboLab and joint academia-industry education modules for both formal and non-formal education. The Tampere RoboLab operates with similar principles as e.g. Fab Labs (fabrication laboratories), but the focus is on indoor stationary and mobile robotics. Aside from education, the concept allows system interoperability testing and pre-competitive research to be done in the same premises as well as field robotics by providing the state of art localisation and perception sensors, and computation and communication devices. This paper will introduce the concept, used hardware and software configurations, education modules and the forms of industry-academia collaboration.

Living Learning Environments
Thomas Rossmeissl, Erwin Groß, Maria Tzempetidou, Jörg Siegert
Institute of Industrial Manufacturing and Management, University of Stuttgart, Allmandring 35, 70569 Stuttgart, Germany
Fraunhofer Institute for Manufacturing Engineering and Automation, Nobelstr. 12, 70569 Stuttgart, Germany

Learning factories and innovation laboratories are current approaches for the qualification of participants from the field of Industrial Engineering. The focus here is on a transfer of knowledge from research to the manufacturing industry. For more than 10 years different learning concepts and scenarios in the working context close to value creation have been developed and tested in learning factories. The participants can experience new situations through different scenarios and learn from them. These concepts are already being used in vocational education and training courses. In innovation laboratories various technologies and scenarios are being investigated and tested. As an example, a well-known innovation lab in Stuttgart focuses on the working environment of the future. Various demonstrators are used to simulate and present specific scenarios from the manufacturing industry, integrating the respective stakeholders. In this paper, two learning environments are compared and evaluated with regard to their potential applications for qualification. For the analysis, evaluation sheets of training events in the Learning Factory advanced Industrial Engineering (LF aIE) and an exemplary innovation lab in Stuttgart have been used. It assess the different learning environments in terms of their suitability as a qualification tool. Based on this, it will be examined how the current learning systems meet the requirements of a value-added integrated competence development.

Using the IIM LEAD factory to identify countermeasures for the demographic challenge
Matthias Wolf, Patrick Herstätter, Christian Ramsauer
Graz University of Technology, Institute of Innovation and Industrial Management, Kopernikusgasse 24/II, 8010 Graz, Austria

Companies in different industries are facing the same challenge: demographic change. When designing workstations for elderly workers, it is necessary to take into account age-related changes in physical and sensory skills as well as in cognitive or mental capabilities. Although extensive data regarding age-related changes are available in the literature, there is a lack of knowledge on how to prepare for an ageing workforce in many companies. Further, age-related declines are mostly not taken into account in workstation design, hence being a reason for physical overload and sick leave. Thus the identification, assessment, and reduction of physical stress takes on a high priority and is the basis for deriving adequate measures given an ageing population. Although the impact of ageing on workplace design is already being researched, there is hardly any research work known that takes into account learning factories as a potential research resource. The aim of this paper is (1)
to discuss the influences of demographic change on assembly work, (2) to discuss how learning factories can contribute to solutions and (3) to specify possible contributions of our learning factory within this field. The concepts described are and will be developed and applied in the LEAD factory of the Institute of Innovation and Industrial Management at Graz University of Technology.

Introduction of a new product in an operating assembly process at Graz University of Technology’s LEAD Factory

Elias Auburger*, Hugo Karre*, Christian Ramsauer*
*Graz University of Technology, Institute of Innovation and Industrial Management, Kopernikusgasse 24/11, 8010 Graz, Austria

Volatile markets and uncertain future scenarios require the capability to efficiently adapt production volumes according to market needs. The increasing variety of products is driven by a shift towards customer markets. Consequently, companies have to deal with more variants of existing products and steady introduction of new products to meet customer needs. The implementation necessitates knowledge about different strategies to cope with short term product mix changes and the understanding of consequential effects on the production system. The Institute of Innovation and Industrial Management at Graz University of Technology operates the LEAD Factory to enable practice-oriented learning in an environment close to industrial reality. The aim of this research is to discuss a concept how to teach the implementation of a new product in a lean improved assembly process. Therefore, this research outlines (1) strategies to cope with new variants and products in an operating assembly process, (2) the case of the LEAD Factory introducing a new product and (3) based on experiences gained from industry projects and operating the LEAD Factory the respective teaching module “introduction of an e-scooter”. Within the corresponding teaching model training participants will analyze the new product, identify the relevant differences to the classic pedal scooter and determine necessary tools and times for the additional assembly tasks. End product of the teaching module is the implementation of a new production layout and the levelling of the production. In the center of the teaching module is the elaboration of a simulation model to explore the impact of the gathered solutions before physically changing the learning factory.
Using an interdisciplinary demonstration platform for teaching Industry 4.0

Jeffrey Wermann\textsuperscript{a,b}, Armando Walter Colombo\textsuperscript{a,b}, Agnes Pechmann\textsuperscript{a,b}, Maximilian Zarte\textsuperscript{a}

\textsuperscript{a}University of Applied Sciences Emden/Leer, Constantiaplatz 4, 26721 Emden, Germany
\textsuperscript{b}Institut für Informatik, Automatisierungstechnik und Robotic (iZAR), Constantiaplatz 4, 26721 Emden, Germany

Industry 4.0 is based on a set of concepts, technologies and organizational processes affects various areas in engineering education and beyond. It includes internet-based networking of digitized mechatronics components on the shop floor with management and business platforms by applying technologies from the IT sector. Even social aspects are targeted, as the human being is also considered to be a part of Industrial Cyber-Physical System (ICPS). The challenge for educational institutions is to deal with this broad spectrum. Departments and institution with different specialization are required to work more closely with each other to be able to teach the topic of Industry 4.0 in all its dimensions. One of the approaches of the University of Applied Sciences Emden/Leer is to build a platform, where different departments can work on, collaborate and use it to teach the various aspects of Industry 4.0. This platform is called the “Automated Class Room” and is a physical demonstrator, which consists of many different modules from different departments, such as mechatronic machines, simulation tools, management tools, logistics systems which are integrated into an Industry 4.0 compliant ICT (information-communication technologies) architecture. This paper provides an overview about the platform and discusses in depth how it is currently used for teaching Industry 4.0 to different target audiences. It describes in which parts the individual departments and specific courses set their focus and how they can demonstrate the benefits of Industry 4.0 for students but also for visitors of the university and enterprises. Furthermore, the “Automated Class Room” is used as a practical test bed, where students from different departments can learn together how to implement Industry 4.0 concepts and technologies. The paper also gives an overview about how the platform is going to evolve in the future.

Integration of LiFi Technology in an Industry 4.0 Learning Factory

Vasu Dev Mukku\textsuperscript{a}, Sebastian Lang\textsuperscript{a}, Tobias Reggelin\textsuperscript{a}

\textsuperscript{a}University Magdeburg "Otto von Guericke", Universitätsplatz 2, 39106 Magdeburg, Germany

We are currently developing a modular and decentralized learning factory to demonstrate Industry 4.0 and Logistics 4.0 scenarios to both, students and employees from the companies. The factory shall allow the setup and evaluation of any preferred factory layout. One major challenge is the design of an appropriate strategy for communication between the factory modules and the identification of adequate communication technologies. There are two main requirements, which we consider for the communication design. First, the communication shall be wireless in order to reduce the effort for changing the factory structure. Second, the communication strategy shall allow an easy identification of the current factory layout and the interconnection of factory resources. According to our current state of knowledge, we believe that LiFi (Light Fidelity) is a suitable technology to fulfill these requirements. In the paper, we discuss the benefits and drawbacks of LiFi as communication technology and present a concept for the integration of LiFi in our learning factory.

Integration of IT Into a Lean Basic Training: Target Group-Specific Insights and Recommendations

Martin Adam\textsuperscript{a}, Maximilian Hofbauer\textsuperscript{a}, Bernhard Mand\textsuperscript{a}

\textsuperscript{a}Kufstein University of Applied Sciences, Andreas Hofer-Straße 7, Kufstein, Austria

Lean Management and high cost automation are often seen as contradictory. Several studies however have shown that Lean Management and IT can actually match and complement each other. If the overall topic is the evolution of Lean from a simple tool box approach to a Lean 4.0 stage, this paper discusses how IT can be integrated into a Lean Basic Training. The training takes place in a traditional Lean learning factory with a real product and a real value stream. Combining a qualitative and quantitative approach, Lean experts and participants of a Lean Basic Training were asked if they saw any benefit in the use of IT in the training. In addition, they were asked which elements of the Lean training should be supported by IT. By applying inferential statistics, influences of target groups on IT integration were discovered. Among others, integration is
significantly influenced by the companies the participants come from, by their level of education, their Lean experience and their IT affinity. Combining these influences of the target groups with insights from literature and the opinion of Lean experts from local companies, selected aspects of IT integration are discussed. Finally, recommendations are given how IT can be integrated into a Lean Basic Training in a traditional Lean learning factory.

Integrated Concept for Acquisition and Utilization of Production Feedback Data to Support Production Planning and Control in the Age of Digitalization
Philipp Schäfers\textsuperscript{a}, Alexander Mütze\textsuperscript{a}, Peter Nyhuis\textsuperscript{a}
\textsuperscript{a}Institute of Production Systems and Logistics, Leibniz University Hannover, An der Universität 2, 30823 Garbsen, Germany

Digitalization is changing industrial production and is offering huge potential for producing companies. One effect resulting from the increasing presence of information and communication technology in production is the increasing quantity and quality of production feedback data. However, only collecting large amounts of data of data does not lead to high logistical performance and low logistical costs. It is essential to acquire the right data with as little operating expenses as possible, to analyze the acquired data target-oriented and to present the results user-oriented, so that concrete actions can be derived. In practice, this is a challenge for producing companies. To demonstrate the opportunities in this field of action, a concept was developed at the Institute of Production Systems and Logistics (IFA) (Hannover, Germany) and, furthermore, implemented in the IFA learning factory. This paper starts with a short introduction of the IFA learning factory. After that, the paper presents the developed concept in detail, describing the PPC system, the data acquisition using RFID, an order processing support system using ESL and the (real-time) data analysis. In the end a summarizing conclusion is given underlining the importance of an integrated concept for data acquisition and utilization.
Session VI – Mixed Reality and immersive learning environments #2
28.03.2019 – 10.00-10.45 – Haus der Wissenschaft – Session Room B
Session Chair: Dr. Sebastian Thiede

Using Holograms for visualizing and interacting with educational content in a Teaching Factory
Dimitris Mavrikios*, Kosmas Alexopoulos*, Konstantinos Georgoulis*, Sotiris Makris*, George Michalos*, George Chryssoulis*
*Laboratory for Manufacturing Systems & Automation (LMS), University of Patras, Patras 26504, Greece

The Teaching Factory concept utilizes advanced delivery mechanisms and high-grade industrial didactic equipment to offer education content. It connects remotely located engineering teams with teams of students in the classroom or laboratory as work together in a common engineering project in manufacturing. This work investigates the potential of using Holograms as key technology for delivering educational content to the classroom side. The holographic system enables the visualization of complex 3D models in real-size dimensions enabling concurrent 3D visualization of the models to a team of students. A prototype has been implemented that offers the collaboration tools to both sides of the Teaching Factory setup. On the classroom or laboratory side, interaction is enabled through gesture recognition upon a low-cost finger tracking device, while on the factory side interaction as well as visualization is possible using tablet or mobile devices. Both sides can simultaneously interact with 3D object being displayed in holographic and mobile displays. Additional interaction functionality such as display annotations, tree view of the geometrical object and content management is offered through the mobile app.

Development of a training concept for leadership 4.0 in production environments
Sina Helming*, Florian Ungermann*, Natalie Hierath*, Nicole Stricker*, Gisela Lanza*
*wbk Institute of Production Science, Karlsruhe Institute of Technology (KIT), Kaiserstraße 12, 76131 Karlsruhe, Germany

Industry 4.0 and the associated technological change result in far-reaching modifications not only having an impact on a company’s organization, but also on the people within it. Managers thereby play a crucial role as they form one major component of a successful change process. Hence, the presented Leadership 4.0 training concept was developed in order to further qualify and sensitize managers for new forms of leadership in the era of Industry 4.0. The training module allows production managers to understand how leadership changes through Industry 4.0 and which specific aspects should be taken into consideration, especially with respect to employee management. In contrast to existing leadership trainings, the presented training especially focuses on production environments and is therefore primarily carried out within the wbk Learning Factory on Global Production. This way, changes resulting from digitization and Industry 4.0 can be vividly experienced and transferred to the managers’ day-to-day work.

Potentials of Augmented Reality in Training
Sabrina Romina Sorko*, Magdalena Brunnhofer*
*FH JOANNEUM University of Applied Sciences, Institut of Industrial Management, Werk VI-Strasse 46, Kapfenberg 8605, Austria

The technological advances through digitization provide the basis for a new form of life. Targeting the future of work, digitalization will lead to a redesign of jobs, particularly in the manufacturing industry. This changes the requirements on employees, meaning new digital competences. To support employees building up the required competences different technologies such as augmented reality can be used. The aim of the study is to analyze the potential of augmented reality technologies to meet the outlined challenges. To fulfill this objective, this paper detects the potential of augmented reality as an innovative learning medium showing several use cases. It will be shown which different teaching and learning objectives can be achieved through the use of this technology in training with a special focus on practical learning scenarios in the industrial environment. This paper serves to optimize education and training in order to meet the requirements of digitalization more successfully.
Session VII — Learning approaches for Learning Factories #1  
28.03.2019 — 10.00-11.00 — Haus der Wissenschaft – Session Room C  
Session Chair: Dr. Reinhard Pittschelli

Optimization of highly automated production line: An advanced engineering educational approach  
Dimitris Mourtzis³, Dimitris Tsakalos³, Fotini Xanthi³, Vasilios Zogopoulos³  
³Laboratory for Manufacturing Systems and Automation (LMS), Department of Mechanical Engineering and Aeronautics, University of Patras, Rio Patras, 26504, Greece  

As industry attempts to integrate the new technologies of the digitalized era in its current approaches, the re-structuring of the production is imperative. Taking into consideration the plethora of alternatives that are revealed through the Industry 4.0 technologies, it is perceivable that the decision-making procedure has become highly complex. In order to support the decision-making process, software platforms that can analyze the data to provide insights via the investigation of different configurations in a manufacturing system are used. Low cost, low risk and quick data analysis are some of the benefits that render simulation an appealing choice to examine various scenarios for the production line. The industry is well aware of the limitations and challenges of the current production practice. However, the lack of expertise and experience on the emerging technologies and applications makes them hesitant to adopt them in the current practice. In contrast, academia has increased knowledge on the technical aspects including the testing of a wider variety of tools and methodologies, but usually in laboratory environment. Nowadays, considering the rapid technological evolution, the gap between academic and industrial practice broadens over time. In this research work, collaboration under an advanced engineering educational approach is proposed, where the technical knowledge of the university is transferred to a highly automated production line for the manufacturing of thermosiphon systems. This collaboration is beneficial for both parties, providing the industry with the capability to solve modern problems by integrating digital technologies while providing the academia with valuable experience on a real industrial problem. The proposed approach includes remote communication between the two parties, data and knowledge exchange, aiming to re-structure the production line including an additional robot. To validate the proposed design, the productivity of the proposed scenarios is compared with the current throughput.

Building capabilities for agility in a learning factory setting  
Hugo Karre³, Markus Hammer³, Christian Ramsauer³  
³Graz University of Technology, Institute of Innovation and Industrial Management, Kopernikusgasse 24/II, 8010 Graz, Austria  

The average industry profit margins are under continuous pressure for decades, however, due to even more competition in product markets a widespread increase in firm-level volatility has been documented recently. Consequently, the length of industry leadership of firms has declined significantly. In order to survive, companies need to be able to proactively prepare their organizations to fast changing market conditions. One concept of how to deal with today’s uncertain and unpredictable environments is agility. Agility puts people in the center and is dependent on a dynamic state of ambidextrous resource sharing and adapting to change. This literature suggests managers to design and effectively implement practices concerning learning and trainings. Training efforts to enhance agility-capabilities need to be dynamic and experience based. Traditional teaching methods seem to show limited effect. Training participants should have the experience to apply lessons learned, receive feedback and apply again. Experiential learning and its application within a learning factory setting seems to enhance agility trainings. This research examines current availability of training programs of learning factories concerning flexibility in manufacturing. The authors focus on the use-cases at Graz University of Technology’s LEAD Factory and characterize preconditions for effective trainings and an experiential learning environment for participants to fully exploit the potential of agility.
SEPT Approaches for Education and Training using a Learning Factory
Dan Centea, Ishwar Singh, Mo Elbestawi
*McMaster University, 1280 Main St. W, Hamilton, ON, L8S 0A3, Canada

A modern learning factory that implements several technologies included in the Industry 4.0 concept and has a strong experiential learning approach has been developed in the School of Engineering Practice and Technology (SEPT) at McMaster University in Canada. This paper focuses on the educational models used for teaching undergraduate and graduate students, and on the processes used to develop industrial and community sponsored projects in the SEPT Learning Factory. The models through which learning is accomplished in the Learning Factory are presented. Undergraduate learning approaches through capstone projects developed in the SEPT Cyber Physical Systems Learning Centre that includes the SEPT Learning Factory as the hub to support these projects are described. Examples of student projects developed and completed in the Learning Factory are presented. Research projects developed by graduate students who use the Learning Factory for their research work and projects that involve the collaboration of undergraduate and graduate students are also described. The ways in which the learning factory is used for innovation and testing new ideas in cooperation with the industrial and community partners are also presented.

Co-determination – An interdisciplinary concept to train PhD students from different disciplines
Anna Conrad, Henning Ober, Manfred Wannöffel, Bernd Kuhlenkötter
*Ruhr-Universität Bochum, Office of Cooperation RUB/IGM, Konrad-Zuse-Straße 16, 44801 Bochum
**Ruhr-Universität Bochum, Chair of Production Systems, Universitätsstraße 150, 44801 Bochum, Germany

The distribution of cyber-physical systems, crosslinking of data and other transition processes often discussed in the context of Industry 4.0 do not only affect the manufacturing industry but all kinds of work that offer potential for standardization. The Learning Factory of the Ruhr-University in its unique social embeddedness has long since recognized workers' representatives and managers as well as undergraduate students as important target groups to be involved in the transition processes of Industry 4.0, always with a clear focus on industrial production. However, now also PhD students from various scientific backgrounds who plan to leave the academic world to build a career in NGOs, administrations or (industrial) enterprises will get the chance to be qualified in a field affecting everyone: The changes of the working world, of competences, tasks and working conditions, will not stop at the doors of industrial factories. According to the tradition of the Learning Factory of the Chair of Production Systems (Lehrstuhl für Produktionssysteme, LPS) of using a holistic socio-technical approach, PhD students seen as future executive staff will play a key role in organizing and shaping transition processes as well as experience them affecting their own working life. This paper introduces a didactic concept developed in an interdisciplinary cooperation of the Office of Cooperation RUB/IGM and the Chair of Production Systems (LPS) of Ruhr-University Bochum with the support of the Hans-Böckler-Foundation. It aims at imparting theoretical knowledge e.g. on the role of co-determination, the use of assistance systems or forms of knowledge management as well as enabling practical experience in the course of four modules. It tries to raise awareness for chances, challenges, questions, and discussions surrounding the changes in the working world.
Session VIII – Learning in Industry 4.0 and cyber-physical production systems (CPPS)

#3
28.03.2019 – 11.15-12.45 – Haus der Wissenschaft – Session Room A
Session Chair: Prof. Christian Ramsauer

Using a semi-automated job-shop production system model to prepare students for the challenges of Industrial Cyber-Physical Systems

Agnes Pechmann\footnote{University of Applied Sciences Emden/Leer, Faculty of Technology, Constantia Platz 4, 26723 Emden, Germany}, Jeffrey Wermann\footnote{Institute for Industrial Informatics, Automation and Robotics (I2AR), Constantia Platz 4, 26723 Emden, Germany}, Armando Walter Colombo\footnote{University of Applied Sciences Emden/Leer, Faculty of Technology, Constantia Platz 4, 26723 Emden, Germany}, Maximilian Zarte\footnote{Institute for Industrial Informatics, Automation and Robotics (I2AR), Constantia Platz 4, 26723 Emden, Germany}

Though the engineering methods, tools, and standards for Industrial Cyber-Physical Systems (ICPS) have become mature and get more defined, the challenges to apply them to develop production systems towards ICPS remain difficult to grasp for experts and practitioners and even more for students. “Digitalization and Virtualization of ICPS” (DVoICPS) is a subject relevant to different student groups in informatics, electronics, mechanical engineering, and others. To teach the idea behind DVoICPS and to sensitize students to the different challenges of the cyber and of the physical world, a semi-automated job-shop production system (model) was adopted. Three types of products were manufactured with different operations. The student tasks included evolving the legacy system toward an ICPS system with improved production performance indicators. The improvements had to be feasible for the physical model, consisting of fischertechnik\textsuperscript{©} elements. Students also had to describe modules of the system as ICPS components and build an executable virtual module of the evolved system, simulating it. Additionally, the students needed to plan and describe aspects for digitalizing the system itself. This paper describes the learning concept of the teaching module, the challenges of teaching students with different disciplinary backgrounds and the students’ deliverables and learning effects. The paper concludes with summary and proposed changes to the teaching concepts for the next round of teaching.

Integration and testing of the RFID-enabled Smart Factory concept within the Learning Factory

Marko Mladineo\footnote{University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, R. Boskovica 32, 21000 Split, Croatia}, Ivica Veza\footnote{University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, R. Boskovica 32, 21000 Split, Croatia}, Nikola Gjeldum\footnote{University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, R. Boskovica 32, 21000 Split, Croatia}, Marina Crnja\footnote{University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, R. Boskovica 32, 21000 Split, Croatia}, Amanda Aljinovic\footnote{University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, R. Boskovica 32, 21000 Split, Croatia}, Andrej Basic\footnote{University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, R. Boskovica 32, 21000 Split, Croatia}

The Industry 4.0 brought new production paradigms and, among them, the Smart Factory concept is definitely the most important one. Smart Factory concept is based on the integration of the Manufacturing Execution System (MES) with the shop-floor level on the one side, and with the Enterprise Resource Planning (ERP) level on the other side. The popular solution for the product data gathering is the RFID (radio-frequency identification) system. In this paper, the RFID-enabled Smart Factory has been designed and integrated within Learning Factory, and its performances have been tested. Regarding the design of the system, it was made as simpler as possible to enable students to understand it and work on it within Learning Factory environment. The Web application hosted on the Siemens Programmable Logic Controller (PLC) was made for controlling and managing of the RFID system (Turck BL-Ident RFID system). A simple MES was made to connect the data gathered by the RFID system with the ERP system (Venio ERP). The designed solution was integrated into the Lean Learning Factory at FESB, University of Split, and the performances were tested. The weakest point of the system could be the performance of the RFID system. Namely, for reading or writing the data on the RFID tag some amount of milliseconds is needed to successfully do it, in regard to the amount of data. So, the research was made, how fast product, with the RFID tag attached onto it, can pass near the RFID head to have successful reading or writing of the data. Analysis of the test results and conclusions for the workplace design are given.

Manufacturing System Design using Simulation in Metal Industry towards Education 4.0

Dimitris Mourtzis\footnote{Laboratory for Manufacturing Systems and Automation, Department of Mechanical Engineering and Aeronautics, University of Patras, Patras 26500 Greece}, Anastasios Vasilakopoulos\footnote{Laboratory for Manufacturing Systems and Automation, Department of Mechanical Engineering and Aeronautics, University of Patras, Patras 26500 Greece}, Evagoras Zervas\footnote{Laboratory for Manufacturing Systems and Automation, Department of Mechanical Engineering and Aeronautics, University of Patras, Patras 26500 Greece}, Nikoletta Bolli\footnote{Laboratory for Manufacturing Systems and Automation, Department of Mechanical Engineering and Aeronautics, University of Patras, Patras 26500 Greece}

As the industrial requirements change at a rapid pace due to the drastic evolution of technology, the necessity of quickly investigating potential system alternatives towards a more efficient manufacturing system design arises more intensively
Integration of digitization trends in learning factories

Fan Li\textsuperscript{a,b}, Jianxin Yang\textsuperscript{a}, Jianmei Wang\textsuperscript{a}, Shuangshou Li\textsuperscript{a}, Li Zheng\textsuperscript{b}
\textsuperscript{a}Fundamental Industry Training Center, Tsinghua University, 30 Shuangqing Road, Beijing, 100084, China
\textsuperscript{b}Department of Industrial Engineering, Tsinghua University, 30 Shuangqing Road, Beijing, 100084, China

With the evolution of technologies, more and more manufacturing companies are taking the role of supplier and adopter of digital technologies. Engineering teaching and training arrangement should also be adjusted with practical and action-oriented approaches closer to the workplace. Therefore, learning factories have been developed to provide seminar participants with opportunities of learning in a real production environment. In this context, it is possible to transfer knowledge and skill in a very practice-oriented way. The benefits of a real production environment can be used both for academic education of students and training of industry participants. The main objective of learning factories is to convey the complex view of industrial processes and to communicate methods and concepts in order to identify potential for improvement and to implement more efficient processes. The following paper will present an overview of learning factories, followed by an explication of the necessity to integrate digital technologies in learning factories. Then, a specific example of the learning factory at Tsinghua University is presented to illustrate the practice to integrate digitalization trends in learning factories.

Didactic Concept for Increasing Acceptance of Consistent Data Standards Using the Example of Assistance Systems in Assembly

Jannis Stecken\textsuperscript{a}, Matthias Linsinger\textsuperscript{a}, Martin Sudhoff\textsuperscript{a}, Bernd Kuhlenkötter\textsuperscript{a}
\textsuperscript{a}Ruh-Universität Bochum, Chair of Production Systems, Universitätsstr. 150, 44801 Bochum, Germany

In times of increasing variant diversity, there are even higher demands on production. Particularly in assembly, activities can be supported by assistance systems such as lightweight robots or augmented reality glasses. However, a wide range of assembly variants requires the automatic configuration of the assistance systems since manual configuration is not economical. Nonetheless, in order to achieve this automatic configuration, data consistency must be ensured within the company so that data can be exchanged both horizontally and vertically. As especially small and medium-sized enterprises have no experience with consistent data standards, this paper presents a concept to convey these contents with the help of a learning factory.

Consideration of material efficiency in a learning factory

Holger Brüggemann\textsuperscript{a}, Jean-Michel Meier\textsuperscript{a}, Sebastian Stempin\textsuperscript{a}
\textsuperscript{a}Institute for Production Technology, Ostfalia University of Applied Sciences, Salzdahlumer Straße 46/48, 38302 Wolfenbüttel, Germany

Due to steadily rising energy and raw material prices, material and energy costs are a key competitive factor for companies. The conscious and efficient use of material and energy resources can lead to high savings without large investments. By means of the shortage of resources and the high cost of materials of manufacturing companies, a material efficiency training
was developed at the Lower Saxony Learning Factory for Resource Efficiency (NiFaR). The research identified a variety of approaches to increase material efficiency at the level of product development and production. Cross-sectional technologies to increase resource efficiency are well known. However, there is still a large deficit in the general understanding of the process. Therefore, the newly created training to increase material efficiency places special emphasis on lean management and process analysis. The participants learn the way from lean production to material efficient production. The course contents are modular and versatile. In addition to basic knowledge on waste prevention, the focus is still on sustainability, production technologies and the optimization of processes in order to make all processes as material efficient as possible. The theoretical content is taught using practical model examples in the production environment based on a real product.
Session IX – Learning Evaluation #1
28.03.2019 – 11.15-12.30 – Haus der Wissenschaft – Session Room B
Session Chair: Dr. Gerrit Posselt

Ex Post Evaluation of a Learning Factory – Competence Development Based on Graduates Feedback
Patrick Balve^a, Lena Ebert^b
^aHeilbronn University of Applied Sciences, Max-Planck-Str. 39, 74081 Heilbronn, Germany

The problem-based and project-oriented learning factory format of the bachelor’s programme “Manufacturing and Operations Management” at Heilbronn University of Applied Sciences was recently evaluated. The research aimed at answering the questions of how the competence profile required by the industry from the graduates’ perspective looked like, and to what extent the learning factory was able to contribute to those competence expectations. To that end, a survey among the bachelor graduates from 2015 to 2017 was initiated in March 2018. The results of this study not only confirm the general picture gained from the literature that the industry attributes great importance to so-called soft skills, i.e. self-competences and methodological competences. It also shows in detail that the specific learning factory concept at Heilbronn University strengthens, among others, particularly, those aforementioned specialist competences.

Research-based Learning for Skill Development of Engineering Graduates: An empirical study
Rajni Singh^a, Devika Sangwan^b, Christoph Herrmann^b, Sebastian Thiede^b, Kuldip Singh Sangwan^b
^aBirla Institute of Technology & Science Pilani, Pilani Campus-333031, India
^bInstitute of Machine Tools and Production Technology, Technische Universität Braunschweig, Langer Kamp 19b, 38106 Braunschweig, Germany

The engineering graduates should have interdisciplinary knowledge in addition to theoretical knowledge to survive in dynamic industrial environment. Literature reveals that Indian engineering graduates need to develop problem solving, solution development, social skills in engineering graduates. Research-based learning (RBL), one of the outcome-based learning techniques, closes the gap between theory and application. It involves the learner to design, experience and reflect the entire process of learning. Inquiry forms one of the important elements of RBL which also develops creativity and discovering new techniques breaking the monotonous process for solution development. The present study conducted an empirical analysis to examine the role of RBL in skill development of engineering graduates. The participants are the recent graduates of Birla Institute of Technology and Science Pilani, Pilani campus and those who had done thesis/dissertation. Thesis/dissertation involves the learner in research process such as problem identification, hypothesis formulation, design, data collection and analysis, interpretation, critical review, etc. An online survey questionnaire has been used to assess the skills. The results demonstrated that the use of RBL develops and enhances problem solving, domain knowledge, language and communication, communication & information technology, general learning, academic knowledge, attitude, ethics skills. It is also opined that use of RBL and activities will foster to reduce the gap between the skills required in the industry and learned at the university. Thus, it is important to integrate the RBL in engineering curricula to provide exposure and develop required skills.

Influence of metacognitive awareness on engineering students’ performance: a study of listening skills
Devika Sangwan^b, Rajni Singh^a
^aBirla Institute of Technology and Science Pilani, Pilani-Campus-333031, India

Educative learning equips learners not with a mechanical set of skills but with a fertile thinking that enables them to holistically nurture their knowledge and skills. Metacognitive awareness, an advanced understanding and execution of skills helps learners not only acquire knowledge of their own cognitive processes but also manage learning activities. This paper aims to trace the impact of metacognition on the extent of the learning (listening skills), the difference between the levels of understanding (assumed and attained), learning of the performance and application of theoretical knowledge of listening skills among engineering students. The study proposes a five-step AWARE concept of metacognition to help the learners become more aware of and reflect on their learning. The study has used consecutive sampling technique and participants
Students' interactions: Using video data as a mean to identify competences addressed in learning factories

Nine Reining, Simone Kauffeld, Christoph Herrmann

1Institute of Psychology, Department of Industrial/Organizational and Social Psychology, Technische Universität Braunschweig, Spielmannstr. 19, 38106 Braunschweig, Germany
2Institute of Machine Tools and Production Technology, Chair Sustainable Manufacturing and Life Cycle Engineering, Technische Universität Braunschweig, Langer Kamp 19 b, 38106 Braunschweig, Germany

Learning factories foster practically oriented teaching-concepts and therefore, offer excellent opportunities to develop students' competences in self-controlled learning processes (cf. Müller-Frommeyer, Aymans, Bargmann, Kauffeld, & Herrmann, 2017). Two teams of four students each were videotaped for one semester during a research-based team project at a learning factory. The aim of this paper is to examine to what extent the competences identified in the competency model for students working with a learning factory by Müller-Frommeyer et al. (2017) are addressed in students' task-related group discussions. The recorded videos (12,807 sense units) were analyzed using a newly developed coding scheme (act4learning) which focuses on learning-related competences. Additionally, the students filled in questionnaires regarding their computer-related self-efficacy before and after the team project. Overall, all examined competences of the model were addressed in the students' discussions, but in varying extents. The video data shows that interactions are mainly related to professional as well as social competences and rarely related to self-competence. Differences – especially regarding the extent to which professional and social competences were addressed in the meetings – can be found between the two examined groups of students and in different learning settings. The results allow a deeper understanding of the competences students address in their team meetings in research-based projects with a learning factory, and therefore, the competences they can acquire while completing the project. The results further provide the opportunity to continue adapting competence-based teaching concepts at learning factories in higher education.

Hybrid learning environments by data-driven augmented reality

Dörte Sonntag, Georgina Albuquerque, Marcus Magnor, Oliver Bodensiek

4Institute for Science Education Research, Technische Universität Braunschweig, Bienroder Weg 82, 38106 Braunschweig, Germany
5Computer Graphics Lab, Technische Universität Braunschweig, Mühlenpfadstraße 23, 38106 Braunschweig, Germany

Augmented Reality (AR) offers the potential to integrate physical, digital and social learning experiences in hybrid learning environments and thereby to achieve learning gains, higher motivation or improved interaction and collaboration. Moreover, by means of AR, theory- or calculus-based learning and experimental exploration in the lab can be brought closer together. Here we present a data-driven AR enhancement of experiments in an electricity and magnetism lab course, where measurement data such as actual current and voltage, are transmitted to a head-mounted semi-transparent display (HMD). In addition, preliminary evaluation results are presented. An improved technical understanding of the subject and especially more dense interrelations between individual learners conceptions are observed.
Session X – Learning Factory Concepts #3
28.03.2019 – 11.15-12.45 – Haus der Wissenschaft – Session Room C
Session Chair: Prof. Christoph Herrmann

The Learning Factory – A New Stimulus to Enhance International Collaboration
1Faculty of Industrial Management, University Malaysia Pahang, Lebuhraya Tun Razak, 26900 Gambang, Pahang, Malaysia
2ESB Business School, Reutlingen University, Alteburgstraße 150, 72762 Reutlingen, Germany
3The Purdue Polytechnic Institute, Purdue University, 401 Grant St. #150, West Lafayette, IN 47907, USA
4Department of Industrial Engineering, Stellenbosch University, 145 Banghoek Rd, Stellenbosch Central, Stellenbosch 7600, South Africa

The paper describes a new stimulus using learning factories and an academic research programme - an M.Sc. in Digital Industrial Management and Engineering (DIME) comprising a double degree - to enhance international collaboration between four partner universities. The programme will be structured in such a way as to maintain or improve the level of innovation at the learning factories of each partner. The partners agreed to use Learning Factory focus areas along with DIME learning modules to stimulate international collaboration. Furthermore, they identified several research areas within the framework of the DIME program to encourage horizontal and vertical collaboration. Vertical collaboration connects faculty expertise across the Learning Factory network to advance knowledge in one of the focus areas, while Horizontal collaboration connects knowledge and expertise across multiple focus areas. Together they offer a platform for students to develop disciplinary and cross-disciplinary applied research skills necessary for addressing the complex challenges faced by industry. Hence, the university partners have the opportunity to develop the learning factory capabilities in alignment with the smart manufacturing concept. The learning factory is thus an important pillar in this venture. While postgraduate students/researchers in the DIME program are the enablers to ensure the success of entire projects, the learning factory provides a learning environment which is entirely conducive to fostering these successful collaborations. Ultimately, the partners are focussed on utilising smart technologies in line with the digitalization of the production process.

TU Wien Pilot Factory Industry 4.0
Martin Hennig, Gerhard Reisinger, Thomas Trautner, Philipp Hold, Detlef Gerhard, Alexandra Mazák
1TU Wien Pilot Factory Industry 4.0, Seestadtstraße 27, 1220 Vienna, Austria
2TU Wien, CDL-MINT, Favoritenstrasse 9-11, 1040 Vienna, Austria

Driven by present megatrends like digitization and demographic change, Learning Factories all over the world are gaining recognition in science, industry and society. In these collaborative learning environments, students and interested trainees from industry acquire methodological, social and personal competencies for future challenges in production. TU Wien Pilot Factory Industry 4.0 (in short TU PF) is a Pilot, Demonstration and Learning Factory, aiming to provide companies a fundamental insight into Industry 4.0 techniques, applications and associated challenges through exemplary implementation of a digitized production environment as well as subsequent research, workshops and presentations. Thereby a focus is set on information and communication technologies (ICT) particularly, to realize the production of customer-specific products in small lot sizes. In contrast to other Learning Factories, TU PF emphasizes not only on teaching knowledge, but also on the demonstration of novel production concepts as well as the development, implementation and evaluation of prototypes together with industry partners. This paper gives an insight into the current status of TU PF and its consistent information flow from engineering to production.

SMEs can touch Industry 4.0 in the Smart Learning Factory
David Grube, Ali A. Malik, Arne Bilberg
1University of Southern Denmark, Alsion 2, Sonderborg 6400, Denmark

This paper describes how a Smart Learning Factory enables manufacturing SMEs of capturing the benefits of highly complex tools and enablers such as virtual simulation and the Digital Twin. The collaborative factory design approach is enabled by embedding the use of discrete event simulation connected with physical objects placed on a Digital Twin Module (DTM). The users can manipulate the physical objects as physical counterparts to the machines and equipment in the virtual space.
and visualize the designed factory and make further analysis. The method combines the use of dynamic discrete event simulation seamlessly connected with physical objects placed on the DTM to enable collaborative design. The bridging between simulation and physical objects is done by using a digital integration platform. Using physical artifacts as counterparts of the virtual objects in the simulation, participants confidently interact with the simulation regardless of skills and competencies. The Smart Learning Factory is helping SMEs to get inspired using physical and virtual simulations for factory design and re-design, and develop solutions in a collaborative environment. This is in-line with the theory of lean automation, that suggests making simple and cheap automation and automating the correct value-adding processes. A demonstration case of designing a production setup in cooperation with a SME is developed and documented.

Self-organization of changeable intralogistics systems at the ESB Logistics Learning Factory
Jan Schuhmacher, Vera Hummel
*ESB Business School, Reutlingen University, Alteburgstraße 150, 72762 Reutlingen, Germany

The persistent development towards decreasing batch sizes due to an ongoing product individualization, as well as increasingly dynamic market and competitive conditions lead to new changeability requirements in production environments. Since each of the individualized products might require different base materials or components and manufacturing resources, the paths of the products going through the factory as well as the required internal transport and material supply processes are going to differ for every product. Conventional planning and control systems, which rely on predefined processes and central decision-making, are not capable to deal with the arising system’s complexity along the dimensions of changing goods, layouts and throughput requirements. The concepts of “self-organization” in combination with “autonomous control” provide promising solutions to solve these new requirements by using among other things the potential of autonomous, decentralized and target-optimized decision-making. A major enabler for the development towards autonomous changeable intralogistics systems are intelligent logistical objects (e.g. smart products, bins and conveyor systems) which are able to communicate and interact with each other as well as with human workers. To investigate the potential of automation and human-robot collaboration for intralogistics, a research project for the development of a collaborative tugger train has been started at the ESB Logistics Learning Factory in line with various student projects in neighboring research areas. This collaborative tugger train system in combination with other manual (e.g. handcarts) and (semi-)automated conveyor systems (e.g. automated guided forklift) will be integrated into a dynamic, self-organized scenario with varying production batch sizes to develop a method for target-oriented self-organization and autonomous control of intralogistics systems. For a structured investigation of self-organized scenarios a generic intralogistics model as well as a criteria catalogue has been developed. The ESB Logistics Learning will serve as a practice-oriented research, validation and demonstration environment for these purposes.

Learning factories as laboratories for socio-technical experiments
Nina Tvenge, Kristian Martensen and Halvor Holtskog
*Norwegian University of Science and Technology, PO box 22, 2802 Gjovik, Norway

Production systems might be viewed as complex socio-technical systems. A central part of socio-technical systems theory, is that improvements demands joint optimization of both the technological and the social parts of the system. Current research on socio-technical systems are, however, mostly interpretivistic with focus on qualitative and descriptive studies of existing manufacturing systems. Learning factories are full scale manufacturing simulators where it could be possible to perform experimental studies on socio-technical systems. This paper discusses the methodological aspects of such experiments and relates the discussion to 15 years experiences from a hospital simulator.

The Teaching Factory Network: A new collaborative paradigm for manufacturing education
Dimitris Mavrikios, Konstantinos Georgoulas, George Chryssoulidis
*Laboratory for Manufacturing Systems & Automation (LMS), University of Patras, Patras 26504, Greece

The Teaching Factory (TF) has emerged as a promising paradigm for manufacturing education. It operates as a non-geographically anchored learning “space” interconnecting remotely located engineering and student teams that work together on real-life projects. The paper will introduce the concept of the Teaching Factory Network (TFN), namely a large-scale implementation of the TF paradigm within a network of academic and industrial organizations. Following an overview of the key challenges associated with manufacturing education today, the foundation of this work, namely the concept of the
TF paradigm will be shortly presented. On that basis, the paper will define the TFN concept, specify the TFN learning delivery hub, namely the software platform facilitating TFN operations, and discuss implementation aspects.
Energy Storage Technologies to foster Energy Flexibility in Learning Factories

C. Schulze, S. Blume, C. Herrmann, S. Thiede

Chair of Sustainable Manufacturing and Life Cycle Engineering, Institute of Machine Tools and Production Technology (IWF), Technische Universität Braunschweig, Langer Kamp 19b, 38106 Braunschweig, Germany

One of today's urgent challenges for engineers all over the world is the expansion and integration of renewable energy resources for electricity generation. Enabling production systems to deal with the fluctuating character of renewable energy, the development of novel strategies to flexibilize the energy demand of factories is a crucial task in engineering business. Beside demand side management of production machines, the integration of energy storage technologies in process chains and technical building systems (TBS) has become a promising strategy to foster energy flexibility in production systems. Towards practice-oriented education, learning factories are established as beneficial concept for research-based learning, not only for universities. However, the urging field of energy flexibility does not yet play a major role for learning factory topics. In order to equip engineers with necessary skills to solve future challenges of increasing renewable energy generation, this paper presents a concept to foster energy flexibility in learning factories focussing the application of energy storage technologies. In this context, two hardware systems featuring energy storage technologies, one based on supercapacitors (SC), second based on lithium-ion battery (LIB), are developed for integration in the electricity supply of the learning factory environment. Furthermore, an energy management system is integrated as centrepiece of the compressed air and electricity supply of a full process chain, whereas the SC is demonstrated as uninterruptible power supply for a single process. The concept and application of energy storage technologies are exemplary applied in the environment of “Die Lernfabrik” at the IWF, TU Braunschweig.

Application of robotics in rail car manufacturing learning factory: A case of welding complex joints

John Ogbemhe, Khumbulani Mpofu, Nkgatho Tlale, Boitumelo Ramatsetse

Department of Industrial Engineering, Tshwane University of Technology, Pretoria West, 0183, South Africa

The use of a learning factory creates a platform for putting to use research innovations, directly into industrial practice. Railcar manufacturers are migrating to fully automated and innovative solutions with industrial welding robot systems playing a pivotal role in the paradigm shift for tasks such as the production of bogie frames and their components. Furthermore, the skills required for bringing about the automation of dangerous and dirty task in the railcar industry are scarce. There is pressure from stakeholders on how researchers and manufacturers can be more efficient in developing a theoretical and practical application framework for a real-time production in the railcar manufacturing industry. Therefore, researchers must look for ways to transfer and demonstrate the application of robotics research in the shop floor with causing disruptions. In addition, there is a need to develop appropriate and customised skill transfer solutions for both smaller and large business owners especially for tasks that are boring for humans. This paper presents an offline-line scheme for building robotic arc welding cell using device task definition and workbenches of the Delmia V5 Robotics, within the learning factory framework.
IoT, IIoT and Cyber-Physical Systems Integration in the SEPT Learning Factory
Ishwar Singh\textsuperscript{a}, Dan Centea\textsuperscript{a}, Mo Elbestawi\textsuperscript{a}
\textsuperscript{a}McMaster University, 1280 Main St. W, Hamilton, ON L8S 0A3, Canada

The SEPT Learning Factory (LF) is a state-of-the art learning environment for students with a focus on designing, prototyping, manufacturing, and testing processes that incorporate key aspects of IoT, IIoT, and Industry 4.0. The infrastructure to support the operations of various cyber-physical system components in the LF consist of critical elements such as computing and networking components. The prototyping and production system components are integrated with digital technology components. This paper describes the use of these elements in the LF. Several messaging platforms used for implementing IoT and IIoT protocols are available to students for data collection, visualization and analytics. This paper describes the use of these protocols, the implementation and integration of IoT and IIoT stations, cyber-physical system control stations, manufacturing machines and collaborative robots.

Servitization trend in the machine-tools market: comparing value from turnkey and specialized IoT-based analytics solutions using TOPSIS
Philippe Legault\textsuperscript{a}, Luis Antonio de Santa-Eulalia\textsuperscript{a}, Elaine Moscon\textsuperscript{b}, Fanny-Ève Bordeleau\textsuperscript{a}, Christian Francoeur\textsuperscript{c}, Nathalie Cadieux\textsuperscript{a}, Rosley Anholon\textsuperscript{a}, Zine Rekik\textsuperscript{c}
\textsuperscript{a}École de gestion, Université de Sherbrooke, 2500 Boul. de l'Université, Sherbrooke, J1K 2R1, Canada
\textsuperscript{b}Technische Universität Bergakademie Freiberg, Akademiestraße 6, Freiberg, 09599, Germany
\textsuperscript{c}Cégep de Sherbrooke, Pavillon 2, Sherbrooke, J1E 4K1, Canada

In the context of Industry 4.0 and the Internet of Things (IoT), machine-tools producers are adopting servitization as a way to develop and sell new specialized data-oriented services already imbedded in their machines, providing analytics. However, large companies producing automation services and products offer generic turnkey IoT-based solutions, which can be implemented in any type of machinery to extract data and provide analytics. These generic solutions can be an important threat to the specialized ones, mainly those developed by SME manufacturers. In this context, this paper aims to investigate to what extent specialized solutions can be compared to generic solutions regarding perceived value. We performed an exploratory study employing a case-based method combined with TOPSIS, in which known generic solutions are compared to one specialized solution provided by a machine-tools producer SME. From the academic point of view, our results provide a better understanding of the requirements of an IoT-based analytics solution in the field. In addition, we propose an approach that can be used by other researchers for value-added analysis of companies embarking on a servitization process. Practical contributions include a method allowing manufacturer to make an informed decision about the solution to be selected for their factories. Moreover, machine-tool manufacturers and service providers will be able to better identify and evaluate their strengths and weaknesses. This project was performed in the context of a living lab for Industry 4.0 and its results are being employed to create a learning factory for research, development, education and training purposes.

A knowledge-based approach to the IoT-driven data integration of enterprises
Mehdi Mahmoodpour\textsuperscript{a}, Andrei Lobov\textsuperscript{a}
\textsuperscript{a}Automation Technology and Mechanical Engineering, Tampere University, Korkeakoulunkatu 7, 33720 Tampere, Finland

Internet of Things (IoT) as a state-of-the-art technology has introduced businesses to new possibilities, thus allowing them to increase the efficiency and productivity of operational processes. Furthermore, the experiences gained by the employees of an organization can be shared among multiple corporations to facilitate the educational processes for employees through establishing learning environments within their businesses. In this study, we discuss the opportunities that IoT offers to businesses to integrate and share the massive amount of data generated by learning factories in enterprises as well as ongoing challenges in this domain. We further present the design and implementation of an ontology-based architecture for the development of IoT solution facilitating the collaborative business-to-business (B2B) knowledge sharing among enterprises to be used in their learning factory environments for educational matters. The proposed solution in this paper allows organizations to pursue their didactic purposes through the creation of an effective learning environment.
Session XII – Digital Learning #1
28.03.2019 – 14.30-16.00 – Haus der Wissenschaft – Session Room B
Session Chair: Prof. Dieter Kreimeier

A case study based digitalization training for learning factories
Maria Hulla¹, Markus Hammer², Hugo Karre³, Christian Ramsauer⁴
¹Graz University of Technology, Institute of Innovation and Industrial Management, Kopernikusgasse 24/II, 8010 Graz, Austria

The manufacturing industry is undergoing a transformation towards digitalization. This change in the potentials, challenges and requirements of industrial companies is accompanied by a shift in the competencies required for the future workforce which, in turn, demands specific training. In the recent years, an increasing number of learning factories address the topic of digitalization. Nevertheless, the content of already existing training sessions mainly involves demonstrations of technologies rather than encouraging participants to develop their own creative solutions and implement them. For this reason, a digitalization training program has been developed in the LEAD Factory of the Institute of Innovation and Industrial Management at Graz University of Technology. This training program includes a case study and consists of alternating and complementary theoretical and practical training sessions. The aim of this paper is to summarize the current research concerning competencies that will be required from the future workforce, introduce the case study method as a part of digitalization training programs for learning factories and discuss whether a case study is a reliable complementary tool for the use of training programs in learning factories.

Database learning of influencing factors in order specific transition times
Günther Schuh¹, Jan-Philipp Prote², Marco Molitor³, Frederick Sauermann⁴, Seth Schmitz⁵
¹Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University, Campus-Boulevard 30, 52074 Aachen, Germany

Manufacturing companies are faced with increasing customized product individualization in the last decade. To flexibly adjust manufacturing systems to customized orders, producing factories are challenged to achieve high adherence to delivery dates (ADD) and short throughput times (TPT). TPT mainly consists of non-value-adding transition times (TT), which make up to 95% of TPT in production. In factories, the calculation of TT is mostly made without considering all situational shopfloor conditions and influencing factors. Results are increasing deviations between predicted and real TT (respectively TPT) and thus decreasing ADD. This paper presents a methodology for database identifying influencing factors in order specific TT. Scientifically, the methodology roots on the Cross-Industry Standard Process for Data Mining (CRISP-DM) and includes filter and wrapper as feature selection methods for data mining (DM). The methodology considers factory specific characteristics, identifies relevant and non-redundant features as key factors and continuously integrates factory employees in the learning process.

Development of an easy teaching and simulation solution for an autonomous mobile robot system
Vinu Vijayakumaran Nair¹, Daniel Kuhn, Vera Hummel²
¹ESB Business School, Reutlingen University, Alteburgstraße 130, 72762 Reutlingen, Germany

With mass customized production becoming the mainstream, industries are shifting from large-scale manufacturing to flexible and customized production of small batch sizes. Agile manufacturing strategies adopted by SMEs are driving the usage of collaborative robots in today's factories. Major challenges in the adoption of cobots in the industry are the lack of a highly trained workforce to program the robot to perform complex tasks and integration of robot systems to other smart devices in the factory. In addition, the teaching and simulation by non-robotics experts of many industrial collaborative robot systems like the KUKA LBR iiwa is a major challenge, since these systems are designed to be programmed by robot experts and not by shop floor workers or other nonexperts. This paper describes the research and development activities done for reducing the barriers in operation and ensure holistic integration of LBR iiwa cobot in the assembly on the example of the ESB Logistics Learning Factory. These include a visual programming solution for the easy teaching of various tasks. Robotics tasks are classified based on common robotics applications and application-specific blocks abstracting specific actions are implemented. A factory worker with no programming competency could create robot programs by combining
these blocks using a Graphical User Interface. In addition, a simulation solution was developed to visualize, analyze, and optimize robotic workflow before deployment. An autonomous mobile robot is integrated with the LBR iiwa to improve reconfigurability and thus also the productivity. The system as a whole is controlled using an event-driven distributed control system. Finally, the capabilities of the system are analyzed based on the design principles of Industrie 4.0 and potential future research ideas are discussed to further improve the system.

Audit - and then what? A roadmap for digitization of learning factories
André Ullrich¹, Judith Enke², Malte Teichmann³, Antonio Kreß⁴, Norbert Gronau⁵
¹University of Potsdam, August Bebel Str. 89, 14482 Potsdam, Germany
²Technical University Darmstadt, Otto-Berndt-Str. 2, 64287 Darmstadt, Germany

Current trends such as digital transformation, Internet of Things, or Industry 4.0 are challenging the majority of learning factories. Regardless of whether a conventional learning factory, a model factory, or a digital learning factory, traditional approaches such as the monotonous execution of specific instructions don’t suffice the learner’s needs, market requirements as well as especially current technological developments. Contemporary teaching environments need a clear strategy, a road to follow for being able to successfully cope with the changes and develop towards digitized learning factories. This demand driven necessity of transformation leads to another obstacle: Assessing the status quo and developing and implementing adequate action plans. Within this paper, details of a maturity-based audit of the hybrid learning factory in the Research and Application Centre Industry 4.0 and a thereof derived roadmap for the digitization of a learning factory are presented.

Concept and case study for teaching and learning industrial digitalization
Elena Mäkiö-Marusik⁶, Armando Walter Colombo⁷, Juho Mäkiö⁸, Agnes Pechmann⁹
⁶University of Applied Sciences Emden/Leer, Constantia Platz 4, 26723 Emden, Germany

The industry faces growing needs of high qualified professionals for the ongoing digitalization of the industrial value chain. The major triggers for the industry to go for digitalization are, among other reasons, the expected higher competitiveness through lower production costs, improved efficiency, shorten time-to-market as well as the needs for mass customization and personalization (extreme customization) of production. The digitalization affects multiple areas simultaneously: technical, social and economic. Coping with the associated difficulties of the digitalization requires professional staff being prepared to face the challenges. This paper describes a novel learning and teaching concept “T-CHAT” that allows engineering students to acquire interdisciplinary knowledge and skills as well as a multidisciplinary view for being able to run industrial digitalization projects successfully.

Digitalized milk-run system for a learning factory assembly line
Sascha Gotthardt³, Maria Hulla⁶, Matthias Eder⁷, Hugo Karre⁸, Christian Ramsauer⁹
³Graz University of Technology, Institute of Innovation and Industrial Management, Kopernikusgasse 24/II, 8010 Graz, Austria

In order to face current trends and challenges in industrial companies such as increasing number of variants, shorter product life cycles and higher product complexity, production logistics is one of the main areas for optimizing assembly systems. To increase the efficiency of the internal material supply, various lean system such as the milk-run were introduced. It has been shown in literature that digitalization technologies can be used to improve lean systems. Nevertheless, there is currently a lack of knowledge about the digitalization of milk-run systems, especially in learning factories. Therefore, this work is introducing a digitalized milk-run system in LEAD Factory, the learning factory of Graz University of Technology. This system relies on the RFID technology to automatically generate orders from a warehouse to a workstation. In the warehouse a pick-to-light system is used to show the logistics employee on a screen which parts to pick. To efficiently deliver the order to the workstation, the shortest path is calculated using a path planning algorithm that is used in robotics. The paper shows (1) developments of milk-run systems, (2) the concept for a digitalized milk-run system at the LEAD Factory and (3) its application within digitalization trainings.
Session XIII – Learning approaches for Learning Factories #2
28.03.2019 – 14.30-16.00 – Haus der Wissenschaft – Session Room C
Session Chair: Dr. Puay Siew Tan

Attaining Learning Objectives by Ontological Reasoning using Digital Twins
Joe David², Andrei Lobov⁴, Minna Lanz⁷
¹Automation Technology and Mechanical Engineering, Tampere University, Korkeakoulunkatu 7, 33720 Tampere, Finland

Learning Factories provide a propitious learning environment for nurturing production related competencies. However, several problems continue to plague their widespread adoption. This study mentions these issues before proposing the use of digital twins as an alternative. The study presents an approach towards modelling such a digital twin and proposes a solution that uses ontologies to develop a formal representation of the domain (a flexible manufacturing system) and the learning that occurs in the environment. A reasoning mechanism is used to deduce inferences from the ontology to facilitate automated assessment of the learner. A use-case for the pedagogic digital twin is presented and discussed before proposing future directions for work.

Example of a problem-to-course life cycle in layout and process planning at the MTA SZTAKI learning factories
Zsolt Kemény³, Richárd Beregi³, János Nacsza³, Csaba Kardos³, Dániel Horváth³
²Centre of Excellence in Production Informatics and Control at the Institute for Computer Science and Control, Hungarian Academy of Sciences, Kende u. 13-17, H-1111 Budapest, Hungary

MTA SZTAKI maintains two learning, demonstration and research facilities which are both set up to host individual student projects and repeated courses likewise. While the physical setting and facility functionalities do already establish a fundamental context linking both types of activities, recent experience has shown additional potential in building up repeatable courses on the outcome of one-off projects. The paper gives an in-progress overview of a project-to-course development based on equipment designed and built around assembly problems of existing industrial products. It is expected that such interlinking of stand-alone projects and repeated courses will become a recurring part of the operation of the facilities, therefore, a roadmap of a project-to-course life cycle is proposed as a working assumption, pending gradual refinement through subsequent experience and integration of other methodologies.

Learning in Context with Horizontally & Vertically Integrated Curriculum in a Smart Learning Factory
Ragu Athinarayanan⁴, Brittany Newell⁴, Jose Garcia⁴, Jason Ostanek⁴, Xiumin Diao⁴, Raji Sundararajan⁴, Henry Zhang⁴, Grant Richards⁴
³School of Engineering Technology, 401 N Grant Street, Purdue University, West Lafayette, IN 47907, USA

In this work we present the development of a Smart Learning Factory (SLF) at Purdue University for preparing students with the skills, capabilities, and technological experiences necessary to excel in an Industry 4.0 environment. Functionally, the SLF is a replica of an actual cyber-physical production factory designed to intentionally foster collaboration between courses from multiple disciplinary areas, particularly mechanical, electrical, mechatronics, and robotics. Our objective is to reduce course silos by deliberately fusing the interconnection between courses by using SLF as the common unifying platform. Activities in design, manufacturing processes, production, production management, automation, energy, information, and communications, teamwork and collaboration are integrated using a vertical and horizontal integration framework. Unifying project activities were designed and introduced into these courses using this framework. As a result, 22 courses were integrated and a total of 26 vertical and horizontal integrated projects developed. This integration also facilitated the development of an energy credential using the SLF. Students progressing from freshman through senior year in college will better understand the interconnection of content between different courses, apply their learning to a manufacturing environment, gain a holistic perspective of the interdependent structures of the cyber-physical system, the connected enterprise, and the manufacturing ecosystem.
Integration of a Case Study into Learning Factory for Future Research
Kavin Kathiresh Vijayan, Ola Jon Mork, Lars A.L. Giske

Department of Ocean Operations and Civil Engineering, Norges teknisk-naturvitenskapelige universitet (NTNU)—Campus Aalesund, Larsgårdsvegen 2, 6009 Aalesund, Norway
Optimar AS dept. Stranda, Svenmorka 45, N-6200 Stranda, Norway

The concept of Industry 4.0 is currently the leading research topic, and the learning factory (LF) provides a platform for education and research in both academic and industry field. The underlying objective of this paper is to upgrade the existing lab facility at the university to learning factory setting for addressing the local small-to-medium enterprise (SME) challenges in Industry 4.0. Taking into consideration the local fish processing plant (FPP), one of the critical challenges is their cleaning of equipment, and this paper conceptualizes a part of the learning factory for research in the robotic cleaning solution. It also introduces a research project of an already validated prototype of robotic cleaning solution and discusses the opportunity of integrating it in the learning factory for demonstration and teaching, with further optimization using Industry 4.0 approaches.

Uncertainty Management in Advanced Manufacturing Implementation: The Case for Learning Factories
Luiz F. C. S. Durão, Marcos O. Guimarães, Mario Sergio Salerno, Eduardo Zancul

Departamento de Engenharia de Produção, Escola Politécnica, Universidade de São Paulo, Av. Prof. Almeida Prado, Trav. 2, n. 128, 05508-070, Cidade Universitária, São Paulo, Brasil

Novel manufacturing concepts and technologies emerge in the environment of the fourth industrial revolution, also known as Industry 4.0, thus requiring new skills and abilities. However, technologies are associated with uncertainties related to technical specifications of products and production processes. Being able to identify and create strategies to overcome uncertainties is still a challenge to Industry 4.0. In this paper, we argue that Learning Factories are an effective solution to deal with new technologies and learning how to mitigate uncertainties. Learning Factories are testbeds and educational spaces that operate as a prototype for new concepts and technologies. Therefore, the questions that guide this paper are: What are the main uncertainties in Advanced Manufacturing? How can Learning Factories mitigate them? By describing a case, we will discuss concepts to mitigate uncertainties in a Learning Factory implementation.

Subject-oriented learning - A new perspective for vocational training in learning factories
Malte Teichmann, André Ullrich, Norbert Gronau

University of Potsdam, August Bebel Str. 89, 14482 Potsdam, Germany

Due to an increasing demand for individualized products and the resulting high variability in manufacturing processes, flexibility and cognitive skills of human workers are highly important for manual assembly processes. Nowadays, novice workers are often trained by colleagues or foremen in addition to and alongside their main work. Since time is usually scarce and the procedure can be highly variable, one solution for the companies can be the introduction of digital assistance systems. Hence, the focus of this contribution is the initial learning procedure of the assembly of a new and complex product. Therefore, a user study was conducted in close cooperation with an industrial partner to compare the traditional way of training to the self-paced learning with a digital assistance system. During the execution of the user study, objective data was recorded to allow precise measurements of the individual learning progress. Furthermore, the subjective learning experience was assessed using a customized questionnaire and a standardized task load metric. The evaluation of the study results suggests that learning autonomously with a digital assistance system leads to similar performance curves as learning the process through a personal explanation.
9th Conference on Learning Factories