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Mini-factory – a learning factory concept for students and small and medium sized enterprises

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Abstract

More and more educational organizations promote hands-on training models to prepare their students for professional life. Also in the field of engineering the application of case studies and business games is becoming more common, which are intended to simulate the situation in real life giving the students the opportunity to apply their theoretical knowledge in practice. Some universities have just proven the use of so-called “learning factories” in addition to the traditional classroom environment for teaching in planning and the design of flexible manufacturing systems. These learning factories correspond to small and flexible production and assembly units for practice and for training. The Faculty of Science and Technology of the Free University of Bolzano decided in 2012 to set up a learning factory named “mini-factory” with the scope of a more practice-oriented education in engineering. This paper shows the concept of the “mini-factory” and the impressions and results of its application in the lectures. In addition, the paper gives an outlook of the collaboration between university and business giving also to small and medium sized enterprises the opportunity to qualify their personal in the mini-factory infrastructure.

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1. Introduction

Brilliant students opt out of engineering majors for lack of hands-on opportunities to satisfy creativity, and graduates lack communications and teamwork skills critical to business success. They are crying out for hands-on experiences to complement the classroom lecture experience. Students need a place (analogous to a child’s sand box) away from the lecture hall, where they can get their hands dirty [1]. Many engineering students are “visual learners”, much better served by active, visual and tactile teaching methods [2].

The cause of a failed knowledge transfer in Education is often the missing practical application [3]. The acquisition of competence goes beyond the purely theoretical knowledge. It also includes the ability to apply knowledge to solve practical problems. Only when the connection is guaranteed between knowledge and ability for its application, we can speak of competence [4].

The specific objectives of learning factory concepts in an academic environment are to offer a practice-based engineering curriculum, which balances analytical and theoretical knowledge with manufacturing skills as well as hands-on experience in the design of manufacturing systems and product realization [5].

Learning factory laboratories differ from the traditional, highly focused, disciplinary laboratories that are tied to specific courses such as fluid mechanics, electronics, or controls. In learning factories, students are experiencing a product and the related manufacturing and/or assembly process [6].
According to the problems described above in terms of pure frontal teaching in the classroom, the Faculty of Science and Technology of the Free University of Bolzano decided in 2012 to set up a learning factory named "mini-factory".

The aim was to integrate and use the mini-factory lab in lectures of the Bachelor’s degree for Production and Logistics Engineering. In practical lessons, the students should have the opportunity to apply their theoretical knowledge in a real manufacturing situation and environment. Focus of the mini-factory is to simulate a flexible, changeable and reconfigurable assembly line on which a product, multiple products or product variants can be produced. At the same time, there was a concern to be able to represent both manual, semi-automated and automated assembly situations in the laboratory. The elaborated training concept therefore provides both, the design and planning of layout and assembly process as well as the integration of automated assembly elements. The assembly process has been implemented with flexible manual assembly workstations, material supply equipment and a robot station with a highly flexible gripper.

In addition to lessons for students, the mini-factory lab will be used also in future for the implementation of trainings for small and medium-sized companies, which today often have a certain fear of automation and methods of lean production, as these have their origin mainly in large companies. This paper describes the mini-factory-concept and gives an overview of the applied and successfully proven training concept of a manual and semi-automated assembly process of pneumatic cylinders as well as camping stoves.

2. The learning factory concept in Engineering Education

Manufacturing education will be faced with major challenges in the years to come [7]. Due to the rapid changes of products and production systems, students need to be much more rapidly introduced to existing and future methods. In the future, a more practice oriented teaching is required. Therefore, an adaptation in teaching and of the training content and its delivery mechanisms to the new requirements of manufacturing is needed [8]. Their exists the need for young people to be enlightened about the exciting character of manufacturing, with real life problems being addressed under business conditions. Through a “learning factory” or “teaching factory” the real factory could be brought into the classroom [8]. The flexibility and changeability of learning factories has been identified as an important design requirement in order to address a large variety of potential problems [9]. Only by a high degree of convertibility and the possibility of a quick reconfiguration can be simulated various production and assembly processes of different products or even different lot size volumes.

Learning factories usually are a combination of four well-defined elements (see also [9]):

- Manufacturing or assembly process
- Manufacturing or assembly product
- Manufacturing or assembly infrastructure (factory equipment and software systems)
- Teaching methods and approach.

The teaching method is an important part of a learning factory to guarantee a successful learning process. In the last decade, the Teaching Factory concept has gained major interest in the academic environment. In the following will be described some successful realized learning factory concepts in US and Europe.

Especially in the US were realized a number of educational and / or business pilot activities [10, 11, 12, 13]. A known example of a Learning Factory was developed and established already in 1994 with support from a three-year grant from the ARPA/NSF Technology Reinvestment Program in Manufacturing Engineering Education as a partnership of Pennsylvania State University, the University of Puerto Rico-Mayagüez (UPRM), the University of Washington (UW), Sandia National Laboratories and 24 corporate partners. Another recently established learning factory is the ifactory of the Intelligent Manufacturing Systems (IMS) Centre in Windsor (Canada). It is the only one of its kind in North America and the second in the world (the first similar system was established at the University of Stuttgart) [14]. Gradually this educational concept is also becoming increasingly common in European universities and educational institutions. An example of a European learning factory is the Process Learning Factory CiP at the Institute of Production Management, Technology and Machine Tools (TU Darmstadt) used for teaching industry topics about lean production and advanced manufacturing [14]. The Institute for Machine Tool and Industrial Management of the Technical University of Munich operates two different learning factories: a) the Learning Factory for Energy Productivity and b) the Learning Factory for Lean Production [15, 16]. The Learning Factory for advanced Industrial Engineering (aIE) at the Institute of Industrial Manufacturing and Management (IFF) (University of Stuttgart) is focused on the link between digital planning and implementation of the physical model in the laboratory. On digital work stations virtual planning is performed using digital planning tools first. This will be implemented physically by means of manual work stations, robotic cells, transfer modules and RFID-technology [17]. The project KNOW-FACT is one example for a recently implemented learning factory concept introduced by the LMS of the University of Patras, the Politecnico di Milano, the Technical University of Darmstadt, Tecnalia, CSP as well as industrial partners like Volvo and Festo. In this project the factory and the academic sites are connected via internet, so that real-time communication is feasible, while no extra dedicated production facilities for training are necessary, since the actual facilities of the factory itself are considered [18]. Further similar learning factories are installed at BIBA (Institute for Production Systems and Logistics /University of Bremen), the Chair of Industrial Engineering (TU Dortmund), the Chair of Production Systems (Ruhr-University Bochum), the Technologie-Initiative SmartfactoryKL (Kaiserslautern), the Department of Factory Planning and Factory Management (Chemnitz University of Technology) and at the Institute of Production Systems and Logistics (Leibniz University Hanover) [14].
3. Motivation and objectives for the “mini-factory”-laboratory at the Free University of Bolzano

With the establishment of the mini-factory lab, the Free University of Bolzano clearly follows the requirements and demands from the economy and enterprises. They expect from an engineering education not only theoretical knowledge but also practical experience, if only for case study exercises or simulation games. A laboratory for testing, training, and seminars was installed with the focus on the design of a changeable and flexible production and assembly. For this reason, the laboratory is based on elements for the manual assembly and automated elements, like robot stations, to simulate small-series assembly situations as well as semi-automated assembly of larger quantities of different products or product variants. The chosen and introduced physical enablers of changeability and flexibility are explained in section 3. The aim of the mini-factory lab is to provide students and practitioners, by means of a realistic design of a production, the concepts of changeability in a manufacturing and assembly environment.

An additional scope of the mini-factory lab is to meet the students (and in the same way the companies in which they work later), to take their fear of automated assembly. In the region around Bolzano are operating predominantly small and medium-sized businesses, which often have a craft background and are therefore often referred to be called “industrially organized craft enterprises”. The fact that these SMEs companies currently hardly automate and deal too little with issues such as changeability was a motivation for the establishment of the mini-factory laboratory. The laboratory should qualify young and motivated professionals who apply the learned theoretical content and carry then these experiences into the companies. Therefore, the lab will also enable professionals, who have themselves engaged in the programming of robots and the design of flexible as well as (semi-)automated production processes. In this way, the company will receive young Industrial Engineers, which (where possible and appropriate) are ready for automation and are not afraid of their introduction.

4. Mini-factory laboratory – equipment and software systems

The mini-factory lab was set up in 2012 by the Faculty of Science and Technology to support the research area “Industrial Production” as a laboratory facility for research and teaching. In addition to the investments in hardware, the Faculty invested also in software and digital planning tools. The computer laboratory is equipped with four software systems for Virtual Production (see Fig. 1). The software Autodesk Inventor enables digital product development creating 2D drawings and 3D parametrical product models. Further, other two planning tools are used to plan and design the production process and the manufacturing system. Manual assembly systems can be created, configured according to the situation and flexibly be arranged by module libraries using MTpro, a planning tool of Bosch Rexroth. Automated production and assembly processes can be programmed in advance, using the robot offline-programming tool RobotStudio from ABB. In addition, the laboratory is equipped with the simulation software FlexSim, which allows not only a three-dimensional visualization of the production system but mainly enables material flow analysis, queuing analysis and bottleneck analysis.

Once the digital planning of product, production system and production process has been completed follows their implementation in the mini-factory lab. For this, there are currently installed a number of technical system elements for industrial production and assembly (see Fig. 2). The basic equipment of the mini-factory lab includes several manual workstations from Bosch Rexroth for industrial small parts assembly. The tables are equipped with modern electric screwdriver systems and grab containers of different sizes. The manual workstations were selected based on the following and common flexibility and changeability enablers: mobility, modularity, compatibility, universality and scalability. The manual workstations are in part in the Eco-Shape version of Bosch Rexroth. Eco-Shape is a highly flexible plug-in system of tubular standard frames. Through this kind of modular construction, the assembly workstations can be mounted and knocked down very quickly and are compatible to each other as well as to universal/standard aluminum profiles. Lockable wheels guarantee also a high grade of mobility. To illustrate the principle of the one-piece-flow and to show their benefits compared with the transfer of lots, the workstations can be connected in a flexible way with roller conveyor systems. Other elements of this mini-factory are lean kanban flow racks for the application of material commission using the kanban concept. Next to a manual assembly, also automated assembly devices have been integrated into the lab. The actual automation equipment consists of an Adept SCARA robot (i600 Cobra) for pick-and-place operations and a 6-axis ABB industrial robot (IRB 120) for manufacturing, handling, assembly and packaging jobs. The design of the robot stations allows converting these as simple and quickly to the requirements of different products. This includes an enclosure on wheels (mobility) as well as a table with a perforated plate grid.
5. Mini-factory in practise – application in teaching

The mini-factory is used in practice during the lecture of Production Systems simulating in a business game the planning, design, implementation, gradual expansion and optimization of multi-variant and flexible assembly systems. Great emphasis was placed on lean-criteria and a quantity breathing production. In several simulation rounds the students have to analyze different situations (object-oriented, process-oriented, manual and semi-automated assembly) and to measure/evaluate cycle times, lead times, inventories, etc. At the end of the business game the results are compared and discussed within the groups. In the following sections will be explained the simulation of a manual assembly system as well as the integration of automated assembly stations.

5.1. Assembly task 1 – Changeable and flexible manual assembly system

In a first step, the students have to plan, design and implement a manual assembly system, which allows producing two completely different products. Thus, the aim is to encourage the students to build their assembly system as flexible as possible. At the same time, students should also develop concepts for the expansion of the assembly system in terms of an increase of the production volume.

For the exercise, two fundamentally different products were selected. The first product is a Kuhnke pneumatic cylinder with a diameter of 32 mm used mainly for the automation in industrial applications. The double-acting cylinder consists of 22 components (see Fig. 3). The second product to be assembled is a “Bivouac” Camping stove oven of Campingaz. This gas cooker has an excellent stability due to its robust design. The assembly of the cartridge which is sold separately, is not part of this task. The assembly of the stabilizing legs is done thanks to an easy “Clic” system. The gas cooker consists of three sub-assembly groups (legs, aluminum housing, plastic housing) and a total of 19 different components.

The students start first with the theoretical planning of the assembly task on paper and on computer, according to the following steps:

1) Structure and quantity BOM
2) Analysis assembly task and assembly sequence graph
3) Identification of assembly times using the MTM methodology (methods for time measurement)
4) Determination of the cycle times and line balance
5) Layout design and workplace design
6) Digital Planning and three-dimensional visualization of the assembly system by digital software tools.

After planning the assembly system in the classroom follows its physical implementation in the mini-factory lab. In a first simulation round of object-oriented assembly the products are fully assembled at each manual workstation. Here, the effect of the learning curve by an increasing repetition frequency of assembly tasks will be checked and confirmed by means of time measurement. Through the method of video analysis, the students train to analyze single assembly process times by a filmed assembly process and learn to distinguish between value-added and non-value added time (see Fig. 4).
In the first object-oriented design of the assembly system, the focus is on an ideal workplace design and the optimal arrangement of the various assembly components. In a second step the students have to rebuild the assembly system and to simulate a process-oriented assembly cell, in which the various work content is divided on different work stations. It is important to distribute the sub-assemblies on the tables as well as possible in order to achieve a balanced cycle time on every workstation. In several runs the student groups optimize the distribution of work content, minimizing the waiting times on each table and setting the entire cycle time to a minimum. The experience shows that this phase is particularly valuable for students because they can associate theory with practice, by redistributing the work and through the reorganization of the layout, the reduction of gripping ways, through the right selection of grab containers and by the use of suitable assembly tools (see Fig. 5). The assembly time for the pneumatic cylinder as example could be reduced, as follows:

- Object-oriented assembly: 2 min 50 sec.
- Process oriented assembly step 1: 2 min 40 sec.
- Process oriented assembly step 2: 2 min 11 sec.
- Process oriented assembly step 3: 1 min 47 sec.
- Process oriented assembly step 4: 1 min 31 sec.

The design of the automation process was carried out as follows: While the sub-assemblies for the camp stove are assembled on the manual assembly workstations, the robot performs the assembly of the legs to the housing. To enable the automatic handling process specific plastic supports were designed. They were needed to provide both, the housing and the legs in the movement range of the robot. The same robot cell also allows the automatic assembly of the cylinder housing and the piston rod of the pneumatic cylinder. Also for the assembly of the pneumatic cylinders specific plastic supports were produced to provide four piston rods and four aluminum housings. In this way both products can be assembled at the same time without any dead time for setups.

To ensure this assembly process, it was previously necessary to design and produce a flexible gripper, which was able to handle both, the legs of the camping stove as well as the piston rods of the pneumatic cylinder. Therefore, a flexible two-jaw gripper was designed and adapted to the geometric requirements of the single assembly components.
The integration of the robot station resulted in a not significantly reduction of assembly and cycle times due to outstanding investments in the interlinking with manual workstations. The aim of the integration of an automated assembly unit was especially to demonstrate the possibilities of automation and a flexible design of the robot gripper. With the experimental setup shown in Fig. 7, it is possible to assemble alternately both a pneumatic cylinder and a camping stove with a single gripper.

At the end of the simulation, each student group should document and comment the experiment procedure and the results by means of a final report.

6. Outlook – Summer school for students and small and medium sized companies

The laboratory is used today with success both for research purposes as well as for teaching. The game could be used not only in university teaching but also in the training for practitioners in small and medium sized companies and should become therefore an ideal example of a close collaboration between university and enterprises.

After initial discussions with industrial companies in the region, the most of them would be very interested to train their staff in the mini-factory lab. Therefore, the university could offer the companies to qualify their employees in topics such as Lean Production, design of manual production systems, workplace design, material flow optimization, in the field of automation and robotic applications through the infrastructure in the mini-factory lab.

For the next year several new investments are programmed. In 2014 a flexible transport system for interlinking manual and automatic workstations (handling equipment, robots) and machine tools will be installed. In addition an easy-to-use, standalone vision guidance systems (Adept Sight) and a small parts feeder (Adept Flexbowl) will be set up in the next year. The feeder handles a wide array of loose small parts including parts of different shapes and materials. Using the vision guidance system Adept Sight will help to deal with smaller parts and tighter tolerances.

Assuming this new investment a new summer school for students as well as for interested small and medium sized companies, should be developed and set up within 2015 to train the digital planning and subsequent implementation of manual and automated assembly systems.

7. Conclusion

The concept of the learning factory was established and successfully launched in 2012, through the investment in the “mini-factory” lab at the Faculty of Science and Technology of the Free University of Bolzano. The first applications in teaching show great success due to the close connection between theory and practice. For this reason, the mini-factory will be upgraded in the next years offering additional seminars or summer schools for SMEs.

References