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TU WIEN LEARNING & INNOVATION FACTORY FOR INTEGRATIVE PRODUCTION EDUCATION

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Abstract

This paper presents the "Learning and Innovation Factory for Integrative Production Education" as a case study for a modern didactic approach at the Vienna University of Technology (VUT). The developed teaching methodology is combining the advantages of an interdisciplinary, experiences-based and applied approach to knowledge transfer, aiming to enhance the key competences of future industrial engineers. The goal of this program is to teach the entire genesis of a product from product conception to serial production, which is also known as the Product Development Process (Ulrich & Eppinger, 2011) or more comprehensively the Product Emergence Process (PEP) (Pokojski, Fukuda & Salwinski, 2010). Hence, the pilot course was titled "integrative Product Emergence Process" (i-PEP).
This paper illustrates how the potential of problem-based and action oriented learning can be transferred to higher education in industrial engineering by means of an immersive learning environment that was dubbed "Learning Factory". In this context, the case study deals with competence development for industrial engineers and presents the current approach of the VUT-Learning Factory and of its intended future direction.

Key words:
immersive learning environment, problem-based learning, action-oriented learning, hands-on training, industrial engineering education

1 INTRODUCTION

In a knowledge society where demands for skills, competences and expertise constantly increase and change, a solid academic foundation and continuing education is key to allow an individual's performance to keep up with the requirements of the world of work. The rapid advances in technology and an overall growing speed of innovation combined with, decreasing periods of employment and increased economic competition put ever increasing challenges on future employee's basic academic foundations, but moreover stress the need for solid application oriented skills and competences.

One of the key problems of traditional education is to bridge the gap the between what is taught in classroom and what students need in real-life; this is especially true for professional education. To prevail in today's and even more important in tomorrow's working environment, students have to be enabled to hone their skills in a real-life or at least realistic setting, that prepares them to transfer their skills easily into the working world. To tackle these challenges, the traditional approach to professional classroom education has to be changed or at least supplemented by innovative teaching approaches. Especially the broadly application oriented and interdisciplinary subject of industrial engineering lends itself to a practically and application oriented teaching and learning approach (Hempen et al., 2010; Kuhlang & Sihn, 2012)

In the light of recent developments of problem-based education, the Vienna University of Technology realized a learning factory in order to test and implement alternative education and training methods. Chapter 2 of this paper will discuss the broader relevance and the inherent challenges and prospects of learning factories. In Chapter 3 the didactical approach applied is illustrated by means of the case study, that is at the core of this paper. It represents a novel approach that uses immersive learning environments for comprehensive and lasting education in industrial engineering.

The pilot run of the course "i-PEP" was used as a test-bed for the enhancement of higher education for prospective industrial engineers through interdisciplinary and application oriented competence development by means of an immersive learning environment.

The educational project described above is accompanied by a research project about the educational efficacy of such environments in general and more specifically in order to verify and continuously improve the chosen approach and methods. To distinguish the discussion from the usual argument about "effectiveness and efficiency" the authors will subsequently use the term educational-efficacy, as a term that sums up notions usually convey by the phrases efficiency, effectiveness, sustainability, profoundness, etc.

Chapter 4 reflects the results of the case study, especially with respect to the first findings of the research project and the future direction of VUT's Learning Factory.

2 METHODOLOGICAL-DIDACTICAL APPROACHES TO INTEGRATIVE INDUSTRIAL ENGINEERING EDUCATION

Results from studies concerning problem-based and action-oriented learning suggest, that it is possible to substantially increase educational-efficacy in comparison to traditional classroom formats (Stepien, Gallagher & Workman, 1993; Colliver, 2000; Newman, 2004). In this context, several teaching characteristics determine the required didactic approaches. In the presented case study the two key characteristics are:

- interdisciplinarity and
- practice-oriented education

Applied knowledge transfer as key feature of higher education in industrial engineering

In extension of classical economic theory, one could argue that in extension of the production factors "land/natural resources", "labor" and "capital stock", the factor "knowledge" (some authors argue also for a factor innovation) could be seen as a fourth production.

For the reason that knowledge is becoming often the limiting factor in economic progress, companies invest to ensure, to protect and to gain knowledge through knowledge management and knowledge development. Hence, vocational and continuing education is thriving and managers have increasingly problems to find personnel with comprehensive know-how and interdisciplinary skills. Especially in the engineering disciplines, there is high demand for university graduates that show promising potential. However, often a lack of practical experience and an inability to cope with the increased complexity and dynamism that are present at today's workplace create major problems for novice employees. This is not surprising, since their abilities were formed in several years of university education that is mainly characterized by theoretical education in a frontal teaching.

The gulf between learning and work is large. Learning is often seen as abstract, classroom-based and academic. The world of work is seen as concrete, with bosses and customers, profits and machinery (Field et al., 2009). As mentioned above, certain content and specific subject areas in higher education do not lend themselves to the commonly used classroom settings.

Lectures are geared toward the verbal learner and do not take into account the varied learning styles of students. Many engineers are "visual learners" in realty, much better served by active, visual and tactile teaching methods. Many students find little fulfillment or stimulation in the right confines of the lecture hall and drop out of formal engineering programs as result (Lamancusa, Jorgensen & Zayas-Castro, 1997). Learning at universities often results in inert knowledge that does not enable graduates to solve complex and realistic problems in their working life. Transforming theory into practice is a significant challenge for them. Lectures, supplemented by examples from experience, can not completely replace application-orientated knowledge transfer.

The current state of research assumes, that a combination of cognitive (acquisition of knowledge, forming of practical knowledge) and constructivist (individual experience, know-how, testing) learning theories is best for the thematic complex "Learning in Production" (Gruber, Manl & Renk, 1999).

Already Confucius stated: "I hear and I forget; I see and I remember; I do and I understand". Extending from this classic find, from a scientific point of view the learning pyramid forwards the constructivist premise that instruction is more meaningful when it is realistic, engaged and reflective. It diagrams the effectiveness of learning methods involving different levels of auditory, visual, kinesthetic and interpersonal activity, suggesting that the more involved and communicative the instructional task, the more individuals remember as a result (Booth, 2011).

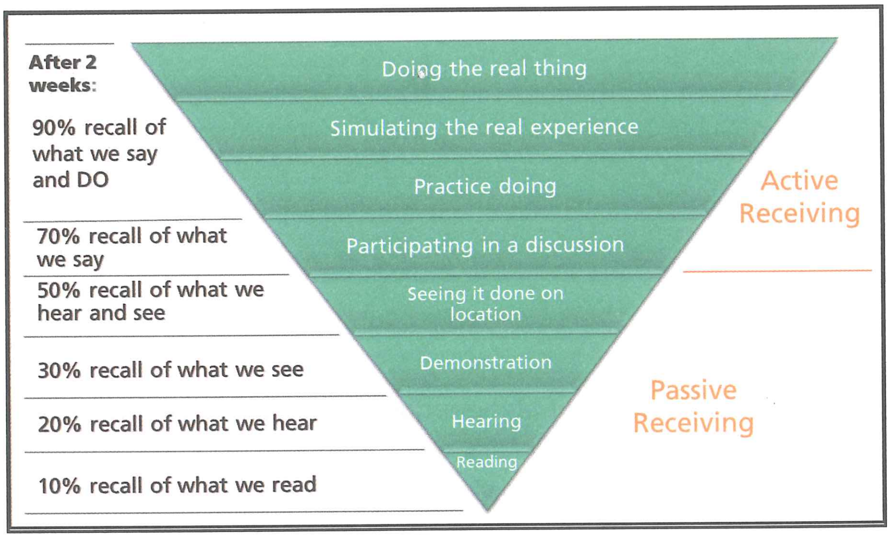

Figure 1: Learning pyramid, reproduced according to (Booth, 2011)

If academic education wants to reflect the learning pyramid depicted above, courses need to be based on direct linkage of theoretical studies with practice-based project for students.

Interdisciplinary teaching approach for sustainable knowledge acquisition

Besides its application orientation, a key element in the education of future industrial engineers is to provide them with an interdisciplinary synopsis, in order to enable them to analyze problems from different point of views and develop comprehensive solutions. Instead of a strictly disciplinary approach, an integral contemplation should enable the students to explore the interrelationships of knowledge, action and problem solving. The foundation for such an interdisciplinary approach has to be laid in education, requiring a substitution of subject-specific instruction to a problem and experience oriented teaching.

A weak „provision of connected learning contents“ is caused by an institution-specific tuition of content. Departments develop objectives for the range of learning content and dominantly adhere to the table of contents of textbooks or curricula. Instructors select the content based on their specific personal knowledge and according to how much importance they put on a specific subject. Currently many lectures follow strict subject-specific topics without promoting any cross-over issues between subject matters.

Instead of subject-specific goals and contents key competencies to be gained should be defined for a results-based instruction! Thus, different subjects are not treated separately but tied in with each other.
Bringing real experience into classroom settings means avoiding traditional teaching in form of teacher-fronted explanatory instruction and aspiring teaching culture by interactive participation. According to this approach, that is also known as "learning by doing", the combination of real-life involvement and experience-based learning is the key factor for success in higher education. Applying this basic didactic approach to industrial engineering means, that an immediate transferability to real-life situations is desirable.

Key competences and skills of industrial engineers

Organizations involved in manufacturing are facing rising complexity in their inside and outside operations and increasing domestic and international competition. Hence, the demands on employees and managers are permanently growing. Beyond a specialized subject, professionals are required to be able to oversee and understand the organization in its entirety, identify cause-effect relationships of the various processes along the value chain, make them transparent and if necessary reengineer them.

Consequentially, the necessary qualifications and competences of an industrial engineer change. Engineering curricula always stressed methods competence, which will not suffice anymore in order to technologically lead and organizationally implement industrial value streams. In fact, a profound knowledge of systemic interrelationships in complex production processes is needed.

According to the Institute of Industrial Engineers "industrial engineering is concerned with the design, improvement and installation of integrated systems of people, materials, information, equipment and energy. It draws upon specialized knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design, to specify, predict, and evaluate the results to be obtained from such systems."

Industrial engineering in organizations (especially in manufacturing companies) deals with the planning, design, implementation and continuous improvement of socio-technical work-systems in order to establish and operate economic value streams and production processes. Thereby industrial engineering technically leads the continuous improvement process and contributes the system, methodological and problem solving competences as well as additionally required key competences (Richter & Deuse, 2011). In this terminology competence implies that individuals are able to successfully apply their traits, skills and knowledge in combination with experiences, values and norms in a self-organized fashion to novel situations (Erpenbeck & Heyse, 2007). To enable an industrial engineer to act proficiently require next to the technical competences additional social key competences as the independent and active participation in task forces, critical introspection and self-reflexion as well as the communication skills in order to work effectively in teams. This is especially important for industrial engineers that are organized in a staff-unit and work temporary as consultants with line-managers (Deuse & Britzke, 2010).

In industrial engineering the term system competence depicts the comprehensive of overall flow and individual performance on a systems level, in order to guarantee a goal-oriented alignment and prioritization of activities. In other words, industrial engineering connects the close to reality depiction of integral processes in production with the capturing and evaluation of dispersions, i.e. in manufacturing or logistics processes and derives conclusive fields of actions. Further, it derives goals and the process goals statuses from the superordinate objectives (strategic objectives, customer goals, factory goals, etc.) of the enterprise.

Problem solving competence in industrial engineering is providing the necessary competence for the goal oriented problem solving and hence the realization of a systematic and continuous improvement process on the basis of a PDCA-cycle. Industrial engineering creates the basis to move from an "as-is state" to a "to-be state" by means of a continuous improvement process.

The *additional key-competences* of industrial engineering encompass personal, activity and action-related as well as social-communicative competences, which enable a professional appearance and operation.

Methods competence in industrial engineering span from the ability to apply the methods of methods-time measurement (or similar systems) and production system for the definition of target states and standards as well as for the deriving of ergonomically relevant data (i.e. stress data) and range to the design of state of the art business process and methods of operation (along the value stream).

On one hand industrial engineers require a well founded methodical and substantiated education in the different areas of industrial engineering. On the other hand the breath of the discipline necessitates a focusing on experience based and practically oriented educational offerings.

Competence development by learning factories as immersive learning environment

Competence development requires an activating teaching and learning environment that makes the learners the protagonists into the focus of the activities. A theoretical basis of such learning environments is the model of experience-based learning of Kolb (Kolb, 1984). This problem-oriented approach to learning can be paraphrased as "learning by doing" and consists of four phases:
Starting with a specific experience with appropriate consequences (step 1) an observation and respective reflexion upon it is made. The subsequent contemplation of the experience leads to an investigation into possible causes of the occurring consequences (step 2). The reflexion finally leads to an abstraction and generalization, that allows the transfer of the experience to different situations (step 3). In the fourth step, active experimentation with the new insights influences the behavior in real situations. Then the learning cycle is run through again.

The objective of the presented approach to teaching and learning is to create awareness for the problems that arise in professional practice and to lay the groundwork for alternative action. By allowing room for experimentation without risk and creating an atmosphere that encourages constructive failure, learning on a meta-level a will be enabled.
The objective of an experiment is to find out, which parameter has what influence on a dependant variable of a defined process (Alberts & Hayes, 2002). The systematic hypothesis testing in experiments is the classic procedure employ by scientists to derive new knowledge (Popper & Keuth, 2005).

The learning factory provides the test-bed to inspire self-directed student exploration. These facilities encourage students to actively experience the following (Lamancusa & Simpson, 2004):

- Apply their theoretical knowledge to solve real-world problems
- Develop common sense and judgment
- Learn to work with individuals of all motivational levels
- Develop an appreciation for other disciplines
- Learn from their own errors and failures
- Discover that usually everything takes longer and costs more than planned

In general the ideas and concepts taught in "learning factories" diverge widely but in the area of industrial engineering education the term "learning factory" is an established term. However synonyms such as "teaching factory" or "method laboratory" are also commonly used, but might also imply a different focus on content or methodical approach.

A learning factory is not only an exercise room or a training workshop for industrial engineering activities to practice certain methods employed in manufacturing and logistics. It is much more than an accumulation of production machines and workbenches, where students learn how to manufacture a product.
It is a learning environment, a place, where learners may work together and support each other as they use a variety of tools and information resources in their guided pursuit of learning goals and problem solving activities (Wilson, 1998).
In the field of competence-based education in industrial engineering, a learning factory is a replication of a realistic factory, especially for mediating skills in production process optimization. It provides an immersive, realistic experimental environment, that allows differentiated teaching and learning methods with an unconventional didactic and methodological approach.

According to the current state of the scientific and technical knowledge, learning factories have been created as pilot factories for competence-based education and training in production. Furthermore, this learning environment is flanked by different information, demonstration and communication segments. As the combination of theory and practice can take place under real conditions, there is a significantly greater authenticity of results compared with traditional cognitive knowledge transfer, followed by a positive impact with regard to both expertise and motivation (Abele & Reinhart, 2011).

The active involvement of the students under real-life conditions is the central focus of the didactical approach of learning factories which simplify models of real processes. They promote open minded learning and combine theoretical learning with practical application. Basic theoretical knowledge gets extended by understanding why actions and decisions have to be a certain way. ("why" and "how")

A learning factory allows a direct approach to (production) processes under changeable and very realistic conditions. Characteristically, the learning content is not exclusively delivered by means of presentation or role-play, in addition the trainees have the possibility to experience the learning content within an authentic (true-to-life) simulation. Own actions and participant's active involvement are a genuine part of the overall concept (Abele et al., 2010).

Due to the integration of elements of practice close to real-life conditions a learning factory facilitates an experimental environment for mulit-purpose training.

3 THE "LEARNING & INNOVATION FACTORY FOR INTEGRATIVE INDUSTRIAL ENGINEERING EDUCATION" AS A CASE STUDY FOR INTERDISCIPLINARY AND PRACTICE-BASED TEACHING

The aim of this case study is to describe an innovative concept for the design of an efficient education environment for cross-disciplinary and practice-based learning for students in the production sector. A central question is how the learning factory and its correlating teaching course can be implemented systematically by using adequate knowledge and technology in order to enable the best possible transferability in possible fields of application.

The interdisciplinary and practice-based approach of the faculty of mechanical and industrial engineering for teaching the "integrative Product Emergence Process"

In 2011, a formal cooperation was formed by three institutes of the faculty of mechanical and industrial engineering at the Vienna University of Technology. The consortium consists of:

- Institute for Management Science / Industrial and Systems Engineering (IMW) in cooperation with Fraunhofer Austria Research GmbH
- Institute for Production Engineering and Laser Technology (IFT)
- Institute for Engineering Design and Logistics Engineering (MIVP)

The partnership was founded in order to develop cooperative activities with the vision of building up a learning factory for cross-disciplinary and real-life education in production. Therefore the alliance set up a strategy plan with common key objectives and goals.

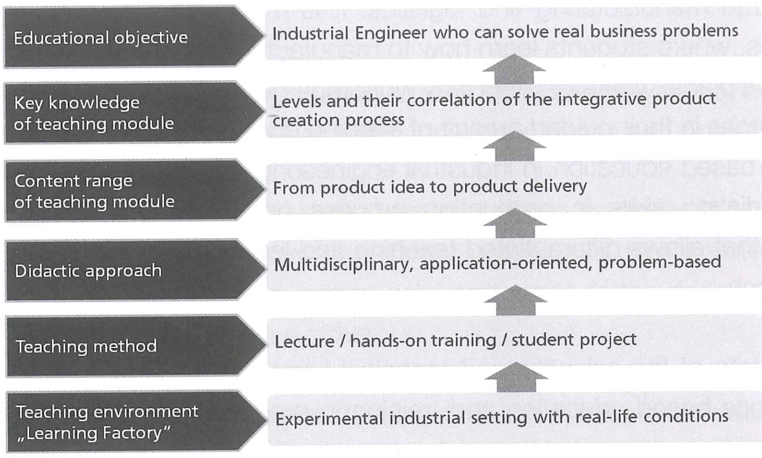

Figure 2: Strategic plan for the "Learning & Innovation Factory for Integrative Industrial Engineering Education"

All three institutes do research in the field of manufacturing but in different specific subject areas. On this basis, the content of the teaching course "integrative Product Emergence Process (i-PEP" was defined. Each institute focuses on a specific part of the integrative product emergence process, which is closely related to the other institutes' subject areas and expertise. The MIVP starts with focus 1, product development, especially construction and design. Focus 2 includes production technology with two main focus points, manufacturing technology and production systems, taught by the IFT. Finally the IMW closes with logistics and assembly within focus 3.

In particular the three institutes provide subjects which are presented in close consultation with the disciplines of the other involved institutes. Partially overlaps in their respective fields of teaching promote the multi-disciplinary approach.

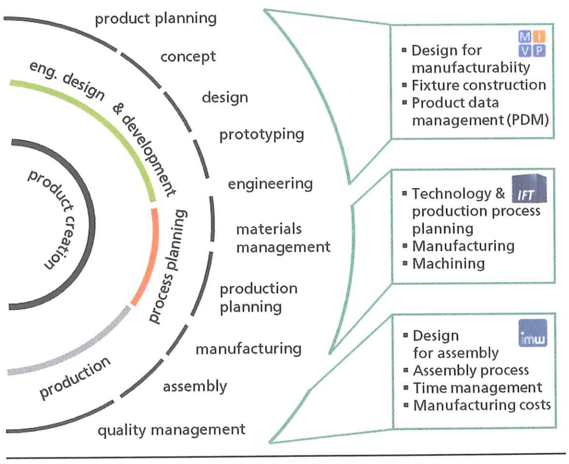

Figure 3: Steps of integrative PEP

The basic idea behind this activity-based course is to give the students the real experience and a broad understanding of the integrative product emergence process, starting with the customer request and ending with the delivery of the developed and manufactured products.

The "Learning & Innovation Factory for Integrative Production Education" as experimental setting for the course „integrative Product Emergence Process"

The physical workspace layout (140m²) of the "Learning & Innovation Factory for Integrative Production Education" is built up of real technological infrastructure with state-of-the-art equipment in order to simulate a real-life factory. It consists of a division for product and process planning with CAD workstations, a manufacturing plant (CNC-machinery, 3D & rapid prototyping printer, laser cutting machine, milling and turning center, coordinate measurement machine, work benches with hand tools, etc.) and an assembly section with flexible mounting stations. The departments are physically connected via receiving and intermediate stores so that logistic aspects, especially the flow of materials, can be simulated. These practice-based facilities permit an improved knowledge delivery mechanism in engineering and production education with a multi-disciplinary didactical character.

Figure 4: Impressions of the "Learning & Innovation Factory for Integrative Production Education"

Student's tasks and learning outcome of the course "integrative Product Emergence Process"

The learning factory at the Vienna University of Technology (VUT) represents the physical educational platform for the learning course "integrative Product Emergence Process", which is part of the syllabus of the bachelor program of mechanical engineering. The course addresses students who are on the verge of finishing their bachelor's degree. The participants have had five semesters of fundamental engineering and basic management education as part of the industrial engineering curriculum.

The course consists of three phases:

The first phase consists of a traditional lecture for theoretical preparation for the tasks to be completed in the following project. The participants receive basic knowledge, that will be practically applied in the project. The theoretical introduction is intended to secure the necessary knowledge base for the subsequent project phase. The first phase is completed with an exam.

The second phase is a student project that persists ten full working days and takes place as a hands-on course in the learning factory. According to the understanding of the teaching method, participants work independently and self-reliant for a defined time on a given assignment. The project aim is to optimize a real product, a prototype slotcar on the scale of 1:24, and its production process in regards to

- lead time of manufacturing and assembly process,
- manufacturing costs and
- fault-free production (quality assurance).

The optimization in terms of driving characteristics takes a secondary role.

The project consists of an exercise to plan, build and optimize a real product and its production process. In this context, the practical course includes product planning and design, engineering, manufacturing, assembly as well as quality assurance.

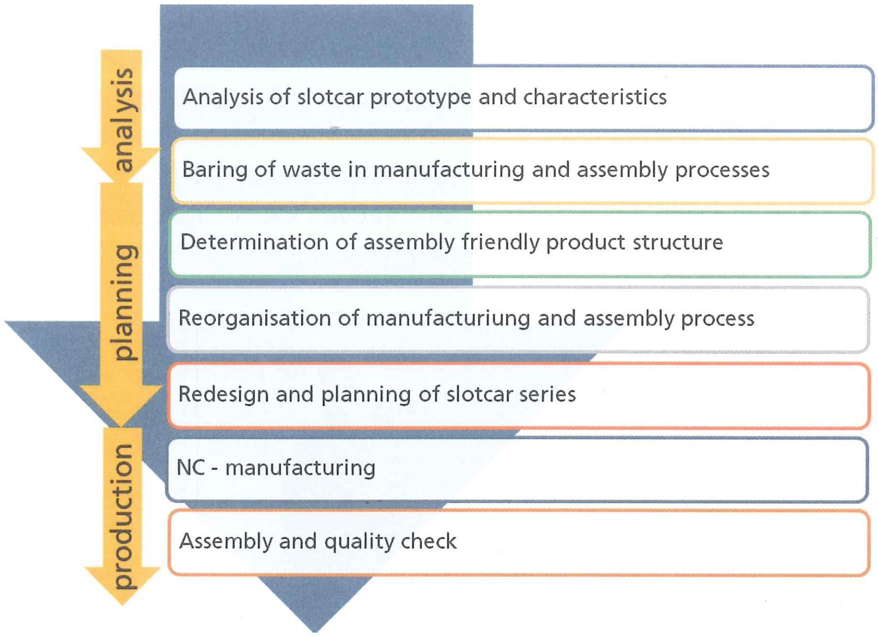

Figure 5: Project tasks addressed in "integrative Product Emergence Process"

The assignments improve the understanding of interrelationships and the influence of coordinated operation of different parts of a company. The participant will be enabled beyond their curriculum to organize production technology in an optimal way. Further, they experience the manufacturing and project related design process and gain realistic business experience with the latest technologies and methods.

Besides the gained technical, analytic and professional skills students can hone their social competence and interpersonal abilities through collaborative problem solving, interdisciplinary team work, focused debate and rotating interim presentations. Further highlights to be pointed out are analytical skills, excellence in project management, ability for structured proceeding, leadership skills, independency, communication skills, flexibility and adaptability as well as creativity.

Students discover the application to solve problems by identifying appropriate methods and learn how to implement them systematically. Participants develop the capability to make decisions on the basis of initial project and product information and experience the realistic results of those decisions. Particularly the impact of decisions made during the product design phase for the production process is experienced first-hand and illustrates the students the challenges of manufacturing in an almost real-life setting.

The assessment of the second step is characterized by several criteria. Besides the gratification of the three mentioned goals related to the product itself and its creation process lecturers evaluate students' behavior, initiative and the development of the competences defined above.

In the third phase students have to prepare a presentation with their project results. This step helps to reflect performed tasks and their influence on the outcome. Upon presenting their results, participant receive both feedback with respect to their performance, possible lessons learnt as well as their presentation skills.

4 IMPACT AND RESULTS

The pilot run of the course "i-PEP" took place in April 2012. Three teams with four students each participated in a series of lectures and spent two weeks in the VUT-Learning Factory according to the described phases in chapter 3. With regards to the set operational objectives of the course, students adduced excellence results. All teams realized a decrease of manufacturing costs between 20-25% and were able to shorten the lead time of manufacturing and assembly processes to about half of the initial time. The objective to guarantee of a fault-free production could not be observed by all teams due to lack in familiarity with the machinery and its characteristics. However, the operating performance of the participants is not the main key evaluation criteria of the course. From a didactical point of view, it is much more important to assess the approach the participants took, to gain their results.

During the practical course students systematically applied methods they had learned in the previous lectures and investigated alternatives on their own. They analyzed the product and its development process from different point of views and implicated different interdisciplinary aspects during the planning phase. All decisions were discussed within the team before arguing the findings in a project presentation.

The manufacturing and assembly processes were impacted by reviews to upstreamed project steps including process re-optimizations and discoveries of new potentials for product enhancements. Thus, participants experienced in a practice-oriented way, that different steps of the PEP are not to be treated separately but tied in with each other.

Facilitators perceived highly motivated students with above-average involvement who pursued gaining best results. This enthusiasm was enforced by the additional challenge of a slotcar-race at the end of the project duration. Teams competed against each other with their self-designed, -planned and -produced slotcars.

After the first pilot run, facilitators and students evaluated its transaction with its minutiae within a final open discussion. Students reported their great experience influenced by an interdependency of social interaction in a technical working system. The VUT-Learning Factory was advocated as an innovative learning environment. A participating student announced his elation by the following comment: „Performing in the learning factory helped me not only to understand methods; hands-on experience gave me tangible access applying methods as in real-life business!" All teams appreciated spending their time actively in the learning factory by working self-directed instead of listening passively in a class room to a lecture. All teams ensured to recommend the course "i-PEP" to their colleagues.

Time expenditure for writing the program script for the CNC-machinery was perceived as a burden by some of the participants. They would appreciate a reduction of components being produced by themselves in order to achieve more time for process optimization.

Finally, the three cooperating institutes conducted an internally analysis of the course "i-PEP". Retrospective, building up the VUT-Learning Factory was the first step to foster action-orientated learning and to increase the quality of education and training at the Vienna University of Technology significantly. On the basis of the observation of the participants during the course facilitators concluded a strong increase of students system, methods, problem solving and additional key competences as mentioned in chapter 2. Chairmen of institutes agreed that this innovative method of experienced based hands-on education enables and ensures the sustainability of the knowledge acquisition and provides enduring learning success.

The main challenge occurred across during the development of the learning factory and the course "i-PEP" was the enormous need for planning efforts by research and project staff. Based on the encouraging feedback, all three institutes decided to establish a second course addressing the master program of mechanical engineering. That course will continue the learning objectives of "i-PEP" that inspired the VUT-Learning Factory team to promote interdisciplinary and experience-based education.

5 CONCLUSIONS

The "Learning & Innovation Factory for Integrative Production Education" serves a stimulative learning environment to intensify student's professional and social competences, performing an innovative platform for creating common understanding between higher education and business reality. This innovative teaching method allows intended industrial engineers to practice and reflect knowledge before entering working life.

The interactive nature of teaching methods, its goal-orientated learning approach and its highly compressed format assist to develop the intuitively skills and competencies that lead to a lasting and sustainable knowledge. Hence, educational quality is increased significantly. Furthermore, learning factorieshelp to enhance teaching methods as well as to elicit tacit knowledge and innovation in organizations of education and higher learning.

This paper elaborates potentials in the field of an action-orientated and experience-based course "integrative Product Emergence Process", using the example of an interactive "hands-on" learning factory at the Vienna University of Technology. The resulting insights are not only relevant for the academic environment, but are also applicable to vocational training and human resources development in industry. Furthermore, the "Learning & Innovation Factory for Integrative Production Education" is used as research- and method-testing facility to develop appropriate services for industrial companies, as well as laboratory for process evaluation and optimization.

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

From 2014 on, The Learning Factory will become the speaking trumpet of this network and annually publish the most relevant proceedings from both the project as well as particular institutions' individual work. This first edition proves the wide variety of Learning Factories existing already today. All of them provide comprehensive education and training on the most relevant learning contents along product and factory life cycles – with different focuses. While most Learning Factories build on industrial infrastructure, others exist only virtually and others again integrate both worlds into a single learning and teaching instrument.

Beyond its educational function, Learning Factories increasingly also serve as research environments – either as a research object itself, allowing didactics and competencies oriented research, or as a research enabler, serving as a test-bed and validation area for new technological or methodological solutions. Therefore, The Learning Factory also includes selected research-oriented contributions.

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