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INTEGRATIVE PRODUCT CREATION – RESULTS FROM A NEW COURSE IN A LEARNING FACTORY

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ABSTRACT

This paper describes a new higher education course "Integrative Product Creation" in the bachelor curriculum of mechanical and industrial engineering and its implementation in the TU Wien Learning and Innovation Factory (LIF). LIF is a faculty-wide cooperation of three institutes combining engineering design, production technology, and industrial engineering aspects. This new didactic approach has an integrated teaching concept with a real product "slotcar" and real processes. The aim of this program is to practice the complete generation of a slotcar from product conception to serial production. The paper presents also the practice oriented learning in the design education regarding the design for X approaches especially applying DFMA (Design for Manufacturability and Assembly). The paper reviews experiences and analyses students work during their practical training to understand the transference of engineering-based knowledge into design practice.

Keywords: Learning factory, integrative product design, design practice, design education.

1 INTRODUCTION

In the last two decades, fresh graduates may not effectively accomplish the product development processes in a life cycle context after an engineering program, even though companies prefer to employ engineering graduates who can implement engineers' tasks without on-the-job training [1]. Moreover, many students don't have enough stimulation and implementation opportunity to perceive their intelligence and creativity in the rigid confines of the lecture hall, which caused students to dropout engineering education without seeing the relevance of their required courses to the actual practice of engineering [2]. These are the key problems of traditional education. The main option for this problem is to bridge the gap between what is taught in classroom and what students need in real-life. Therefore, the teaching and learning settings must be modelled as closely as possible to the actual working context and process with a high degree of realism and clarity [3] [4].

In recent years, many novel practice-based contexts called "learning factory" or "teaching factory" have evolved to provide a new interdisciplinary and real-world problem solving environment in engineering education. Learning factories offer a new approach to understand the interdependency of design and manufacturing in real-world and also provide a balancing between engineering science and practice. The main aim of this approach is removing the traditional boundaries between academia and industrial practice by the combination of lectures with application and hands-on experiences [6] [2]. Learning factories are a solid opportunity in design education for teaching students how to do the design. The design courses at universities could be improved with learning factories depending on the key point ''to learn how to design'' and on the other hand, industrial focus in design of products and systems [1].

To practice design knowledge, design methodology in engineering education and problem solving techniques and also improve the non-technical skills, for example, communication skill and teamwork for this students have to come in touch with a real industrial case. To achieve these goals, a learning factory was realized in order to test and implement alternative education and training methods. This paper is organized as follows. Section 2 describes opportunities to develop competences and skills in the learning factories and design education. In Section 3 the didactical approach and concept of the LIF is presented. Section 4 reflects the results of the case study and summarizes first findings of the participant's experiences. Section 5 concludes the paper and highlights further improvements and future perspectives of LIF.

2 METHODOLOGICAL APPROACHES FOR COMBINING THEORY AND PRACTICE TO IMPROVE COMPETENCES AND SKILLS IN A LEARNING FACTORY

There are a number of learning factories that have been already established worldwide and these are varying in different learning contexts, for example, lean manufacturing, process optimization and energy efficiency [6]. Besides LIF, the learning factories in the German-speaking countries include the Process Learning Factory CiP at the Institute of Production Management, Technology and Machine Tools (TU Darmstadt) focused on manufacturing and lean production [4], the Department of Factory Planning and Management (Chemnitz University of Technology) directed on the Experimental and Digital Factory (EDF) and also the Institute for Machine Tool and Industrial Management of the Technical University of Munich included two different learning factories for Energy Productivity and Lean Production [7]. In contrast to the mentioned learning factories, LIF focuses on practice complete generation of a product from product conception to serial production.

Learning factories have physical and digital environments. The physical environment includes real system components like machining, assembly, logistics. Modelling, visualization tools are parts the digital environment [7]. Therefore the integrative product development in a learning factory has to offer the possibilities to transfer digital models to real products for testing and evaluation. Both physical and the digital environments should be well integrated to create an interdisciplinary and practice-oriented education in learning factories.

As mentioned above, the learning factory with its physical and digital environment provides a teaching and learning concept, capable of transforming theoretical knowledge into practice more effectively. This is a significant challenge for graduates who want to be able to solve complex and realistic problems in their working life. However, students learn at universities often inactive knowledge and this is why students are not able to improve their skills and competences in a realistic setting. The key purposes of a learning factory are improvement of design skills and problem solving competence.

In order to develop competences it needs practice oriented learning environment because that brings the learners into the focus of the activities. Major building blocks of a learning process are shown in figure 1 for a good understanding for the development of competences.

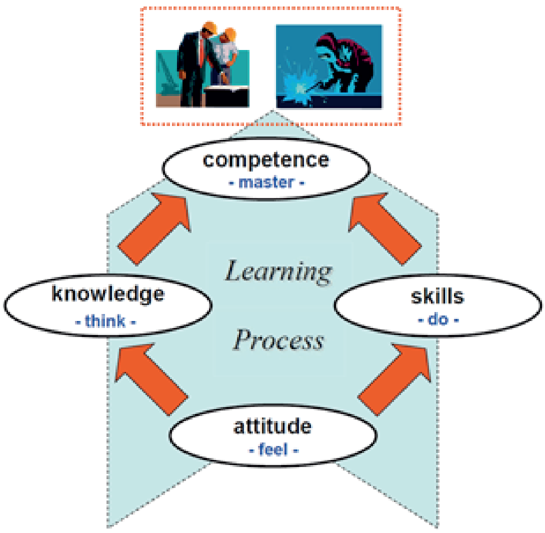

Figure 1.The buildings blocks of the learning process [8]

At this point skill is defined as ability to apply knowledge and use the know-how for the fulfilment of well-defined tasks. It may be cognitive (e.g. creative thinking) or practical (e.g. the use of methods and tools). In the context of a learning process, skills are, for example, observation and replication of actions, task reproduction from instruction or memory and also automated management of activities.

Competence is capacity to handle certain situations or complete a job. It depends on many factors, for example, different types of knowledge, attitudes, self-confidence and social skills [8].

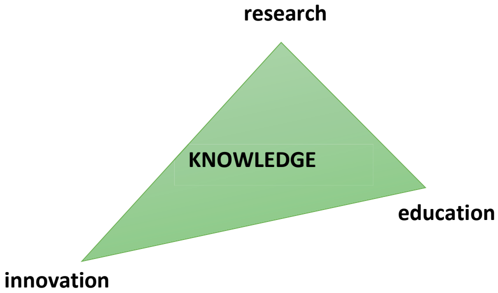

Figure 2. The knowledge triangle in manufacturing [8]

Knowledge, skills and competences are core terms in a learning factory to develop a problem solving capacity. The learning factories provide firstly a bridge between academia and industry and they create an area for the transferring of knowledge from research into innovation or real-life and also develop skills and competences from education into innovation. Therefore, research, education, and innovation (see Figure 2) are fundamental and strongly interdependent drivers of the knowledge-based society [8] and these drivers have to be integrated into a single initiative in order to promote the purposes and future perspectives of the learning factories.

3 LEARNING AND INNOVATION FACTORY: A CASE STUDY FOR INTEGRATIVE PRODUCTION EDUCATION

This part of the paper describes the practice-based and innovative concept of and student's tasks of the course "Integrative Product Creation". Further, it summarizes the aim of the combining learning factory and design for manufacturing and assembly (DFMA) aspects.

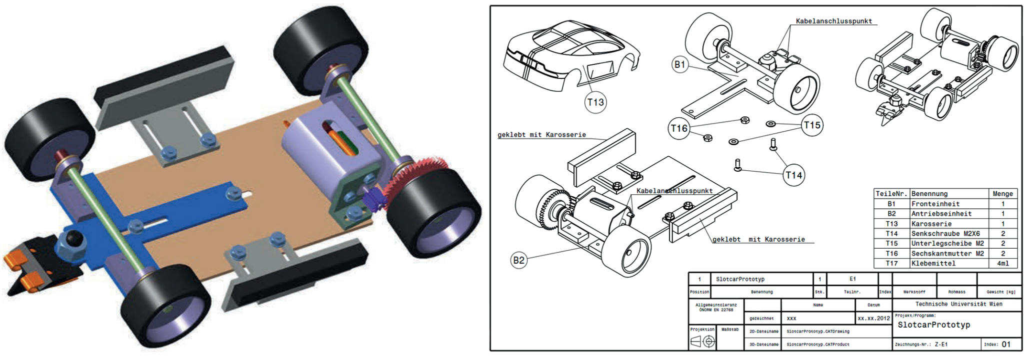

Figure 3. 3D model and assembly group of slotcar prototype

The slotcar prototype was designed and produced (see Figure 3) on the scale of 1:24. It has different components (purchased and production parts) and assembly groups. Therefore, students are able to be flexible to improve the prototype. The context of course consists of planning and design, engineering, manufacturing, assembly and also quality assurance. Figure 4 shows the layout of the LIF and its components regarding the material flow.

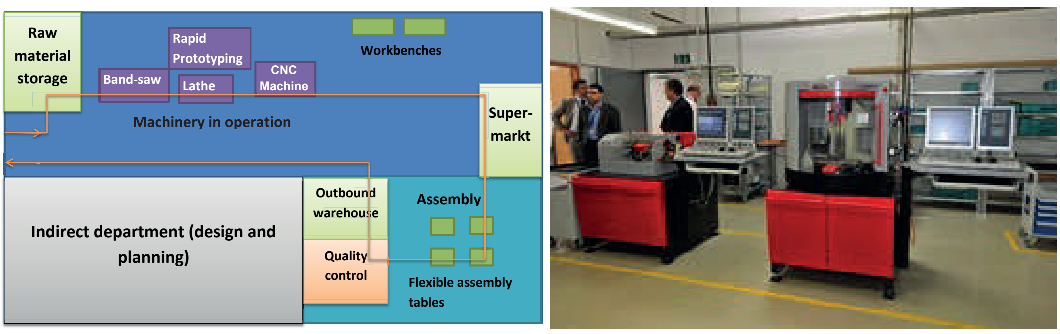

Figure 4. Layout of the Vienna University of Technology Learning and Innovation Factory

The aim of the course is the optimization and development of the prototype for the production of 100 slotcars according to manufacturing cost, lead time of the manufacturing and assembly process, and quality.
In the section of engineering design participants begin with product development, especially design. Each team begins with analysis of the already produced slotcar prototype. Participants firstly focus on structuring of the product and evaluation of design alternatives regarding the design for X approaches. Then they design an assembly fixture and manufacture it with 3D printer, finally they prepare 3D models, drawings, operation and assembly plans for further processes.

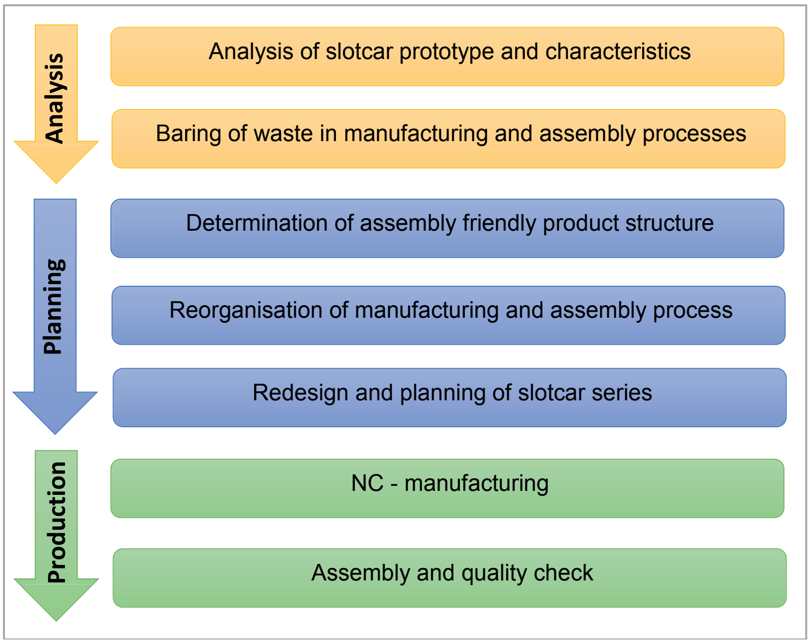

Figure 5. Steps of the Integrative product development

The next section focuses on manufacturing technology and production systems. This includes materials management, operation planning, NC (Numerical control) programming, and manufacturing of the improved parts of the product. And the final section consists of industrial engineering and assembly. Students plan assembly process and operations according to time and quality.
At the beginning, the course includes also a traditional lecture for theoretical preparation of participants to the tasks of learning factory (see Figure. 5). In the lecture, ‘‘Design for X’’ (DfX) methodologies, the DFMA (Design for Manufacturability and Assembly) is considered and emphasized, since both are highly apparent cost reduction drivers in the early stages of product design.

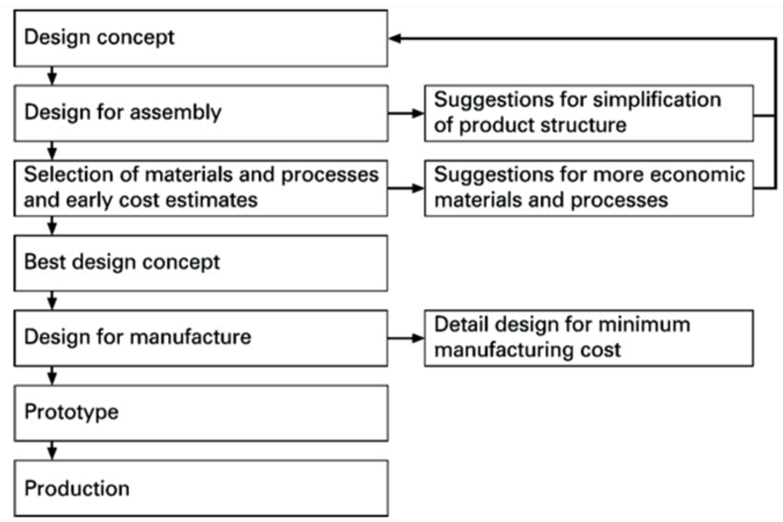

Figure 6. DFMA process [1]

The optimization of manufacturability of the slotcar and the minimization of the effort of slotcar assembly must be considered by the participants according to the DFMA process (see figure 6) in the learning factory. In summary, within the learning factory a team of students develops, plans, and manufactures a real product from prototype to series in for optimizing cost, quality and time. Therefore, the course promotes a holistic consideration of product creation process so that students are able to identify the impact of their design based decisions for the manufacturing and assembly process. Moreover, it combines theoretical learning experiences with practical application and improves knowledge, skills and competences of participants, especially in design engineering.

4 RESULTS OF THE CASE STUDY

In this section, the results and students' feedback in the first two years (2012 and 2013) of our program are described and discussed. Totally seven teams with four students participated in the first two years and after 2 weeks praxis in the LIF according to the described phases in section 3 all students or each team accomplish to develop and produce their own improved slotcars. In figure 7, two different designs of slotcar are shown and these are just two from many optimized slotcars in the LIF.

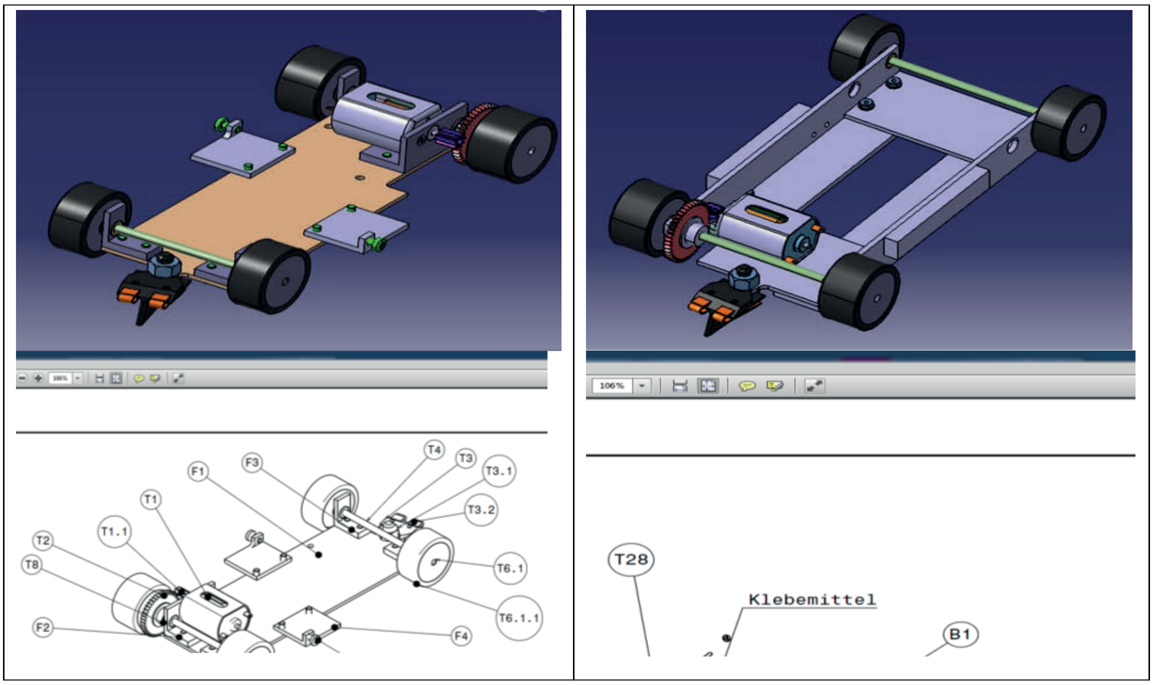

Figure 7. Two new developed and produced slotcars

According to the final presentations of students and their feedback, also observation of facilitator on two weeks practice, the course was very successful. The educational objectives of the course, i.e. the desired skills which we want our students to develop, for example, students were very creative and communicative. Each team improve new slotcar with implementation and optimization of DFMA.

During the course in the LIF students used the methods they had learned in the lectures and all decisions were discussed within the team. Their developments and idea were also discussed with facilitators within a final open presentation. Students reported their experience in the practice-oriented LIF and mostly, they made positive appreciation. Here are some comments from Students: "Applying theoretical knowledge and methods to solve real problems with social interaction in a technical working system was for me the first step in the engineering", "LIF provides a good opportunity to make errors and failures with our knowledge and see the results and learn from them", "It helps to understand methods which we hear and learn in the classroom". After considering students feedback some objectives were improved in 2013 compared to 2012, for example, effective integration of the project management methods.

In the LIF, students analysed the product and its development process from different points of views, and then after discussing their ideas within the team they implemented actively operational objectives of the course and realized their decisions from design concept to production of the slotcar. Each teams achieved a decrease of manufacturing costs between 20 – 25% by applying the DFMA aspects. An important point for the success of the course is final testing and a tournament with the slotcar because the competition aspect generates a creative environment and keeps students highly collaborative and motivated with the challenging racing option with their self-designed slotcars.

5 CONCLUSIONS

In this paper, a new approach for the practice oriented learning is presented with the purpose to highlight the problems from student and academic perspectives within the LIF and also the areas of opportunity for improvement of teaching and learning for the product design program. Most importantly, this approach is a new step for understanding the limits of the realization of engineering-based knowledge into design practice and manufacturing.

The introduced approach for integrative production education is a successful and practice-based engineering curriculum and provides an effective learning environment. The results show that students of practice oriented learning factory have significant advantages over traditional engineering education, because it addresses to balance theoretical knowledge in product design and realization. Moreover, it enables students to develop their professional skills.

Learning factory provides implementation of alternative education and training methods so that it will continue to evolve and expand, it becomes a core part of an engineering education. It is a challenging option to bridge the large gap between learning and work in real-life with its key characteristics such as interdisciplinarity, immersive learning environment, problem-based and action-oriented learning in comparison to traditional classroom formats.

In order to enable a continuous improvement of the course it requires identifying and generating competency-oriented and didactical new strategies that may be employed in the learning factory. At this point, application of design methodologies in integrative production education is very significant because the participants can apply design knowledge more effectively and accomplish creative-design more systematically and rationally.

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