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REALIZATION OF MODERN EDUCATIONAL CONCEPTS IN ENGINEERING DESIGN

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ABSTRACT

This paper gives an overview of engineering design education at University Erlangen-Nuremberg in order to prompt a discussion about the structure and scope of the proposed educational concept compared to other approaches. Due to the transformation of the traditional German degree programs to an educational system based on two cycles (bachelor/master), a new curriculum had to be performed. The curricula and the according lectures were derived based on a review of demands on product developers. This review and the resulting educational concept are presented in this paper. While setting up the lectures, one of the aims for education in engineering design was to build up and emphasize a close relationship between engineering design, engineering mechanics, materials engineering and production technology. Some of the courses, especially a CAD course and a product development and design project, are explained more in detail. In the first mentioned course, a modern way of computer-supported, "blended learning" was realized. In the second mentioned course, new ground was broken by applying subject-specific knowledge in combination with soft skills by offering an obligatory project already in the bachelor program.

Keywords: engineering design education, methodological and practical training, curriculum redesign

1 INTRODUCTION

1.1 Background "Bologna Process"

In 2000, the European heads of state and governance passed a program called "Lisbon Strategy", which has the intent to make the European Union to the most competitive and most dynamic knowledge-based market in the world. An important part of this strategy is the so called "Bologna Process", which describes a political motivated intention to create a consistent European higher education until 2010 [1]. Main objectives of the "Bologna Declaration" from 1999 are [2]:

- Adoption of a system of easily readable and comparable degrees
- Adoption of a system essentially based on two cycles
- Establishment of a system of credits
- Promotion of mobility
- Promotion of European co-operation in quality assurance
- Promotion of the European dimension in higher education

Some more objectives, especially concerning lifelong learning, were later defined in the "Prague Communiqué" and in the "Berlin Communiqué". But the most significant effect of the "Bologna Process" – as a consequence of the first two objectives mentioned above – is a radical transformation of established education systems, particularly the so called "Diplom" degree programs (for example in engineering sciences) or "Staatsexamen" degree programs (for example medical science or law) to a different structured, compared to the "old" systems more or less incompatible education system. This new education system is based on two cycles and it is strongly orientated to the Anglo-American bachelor/master system.

Due to the "Bologna Process", German academic education is in flux for some years, but in the meantime this transformation is widely completed: Since 2007 nearly all students in Germany start in bachelor/master degree programs and a few first alumni with bachelor degrees leave universities. Although there are still resentments concerning this new education system, some German universities leverage the situation to modernize and optimize their curricula. Therefore this paper should prompt a discussion about the proposed structure of Bachelor programs in order to achieve high-quality education in engineering design.

1.2 Evolution of engineering education

At University Erlangen-Nuremberg the new bachelor/master degree program "Mechanical Engineering" was introduced in winter term 2007/2008 to replace the former "Diplom" degree program. In parallel, two other degree programs also were adapted from "Diplom" to bachelor: "Industrial Engineering" and "Mechatronics". The former degree program combines aspects of business economics and mechanical engineering, whereas "Mechatronics" combines aspects of mechanical engineering, electrical engineering and computer science. This takes the demanded diversification of students education into account [3]. Before the curricula were defined, the demands on engineers employed in the field of product development have been analysed. For this, a lot of studies of the Association of German Engineers VDI, statements of the TU9 Group, the German Academy of Science and Engineering acatech or the German Engineering Federation VDMA were regarded. Furthermore, different scientific publications were taken into account. After that, the curricula were structured under consideration of restrictions resulting from "Bologna Specifications" and demands of different German ministries.
The change was used to strengthen the traditional focus of product development and production as well as to build a close relationship between engineering design, engineering mechanics, materials engineering and production technology, already in the bachelor degree program. This should be quite a good basis for a modern interpretation of mechanical engineering, which can be characterized by catchphrases like close interlocking between development and production processes, high extent of reliability or lightweight construction. Regarding these new bachelor degree programs to other German universities based on a comparison of contact hours respectively ECTS-credits, it can be assessed, that University Erlangen-Nuremberg has a very strong position concerning engineering design education (see chapter 5).

2 DEMANDS ON THE PRODUCT DEVELOPER

2.1 General Aspects

Product development and product engineering mean finding solutions and implementing them in an appropriate way. In order to develop products efficiently, product developers and design engineers have to be multifaceted and familiar with a lot of subject-specific, methodological, personal and soft skills [3]. The demanded competencies are heuristic/practice related, branch/subject related, methods related, systems related and related to personal and social behavior [4]. In general an engineer has to possess competency in the analysis and synthesis of technical systems and processes [4]. According to a study of the Association of German Engineers VDI [5], a substantiated subject-specific knowledge is still the most important demand on alumni in engineering disciplines, especially, if they are working in the fields of research and development (R&D) or engineering and design (E&D), Figure 1.

2.2 Subject-specific Basics

Nowadays, product development processes are accompanied and supported by a plenty of methodologies and tools: all engineers, who are involved in product development, have to internalize development processes and procedure models as well as design methodologies and computer-aided tools (CAx) based on digital product models [6]. Therefore students of different degree programs have to be taught a set of basics to be able to communicate safely and work efficiently. Furthermore the demand for knowledge in methodologies and computer aided techniques is arising in general. But also "classical" skills are still important, for example reading and understanding engineering drawings, which have to be taught to students in the different degree programs. The importance of this task is outlined by MIYADERA, Executive Vice President R&D Group of TOYOTA Europe in [7]: "*[...] TOYOTA needs more engineers with hands-on-mentality again, so hands, which are linked with brain. Young engineers, who grew up with CAD have this mentality barely. Hence, we urge our young engineers to do their technical drawings on paper again. This is a very important exercise to raise the awareness of the designed part. This all sounds very primitive, but it is essential for product quality [...]*" (cit. translated from German). WINKELMANN also states *"There is a strong link [...] between the ability to draw and the ability to design."* [8]. Despite the great and still increasing importance of digital product models, 3D drawings and other CA-Techniques, the technical drawing remains an international and judicial tool that has to be understood and used properly. So it is important to give exercises both in engineering drawing and computer-aided techniques as well.

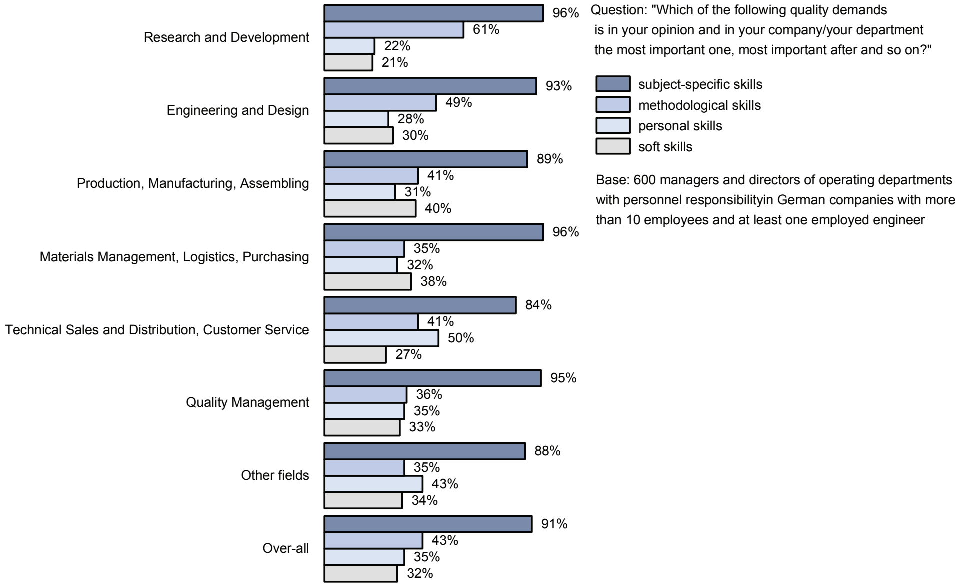

Figure 1. Quality demands on engineers. Source [5]

The representation of the geometric product design is one basic aspect pillowed by other disciplines:

- Engineering mechanics and engineering mechanics of materials
  It is a pivotal task in design education to impart skills of dimensioning of product components based on modeling techniques. Aim of the mechanics of materials is to gain reliable information on the resistance of machine parts against external loads. So fatigue, fracture and impermissible deformation are avoided by appropriate dimensioning.
- Materials engineering
  In order to be able to compare the stresses in constructions with the material properties, knowledge of mechanical properties of materials is required. Moreover information on acoustic, tribological, thermal and electrical properties and their dependence is of interest. An interdisciplinary view on these properties based on chemical mediations allows a holistic view on materials and their importance in product development. This even results in knowledge about technological and ecological material properties.
- Form design
  Form design is a creative productive process which depends on dimensioning and viable material properties. It is one of the crucial cost-dominating tasks in product emergence because it defines a set of required processes along the product life cycle.
- Machine elements
  The collectivities of all constructional elements which cannot be subdivided into further constituent parts regarding functional behavior are called machine elements. They resemble technical solutions based on basic physical principles for recurring fundamental tasks. The knowledge of the function and the mode of operation of machine elements are demanded in industrial product development for proper choice of cost-efficient solutions. In order to select the parts properly fundamental methods of selecting, calculating and designing of machine elements have to be imparted.

2.3 Advanced subject-specific skills

Mechanical engineers, industrial engineers and mechatronical engineers must be able to enhance their basic knowledge in order to gain advanced competence in engineering design. Therefore disciplines like design methodology and design strategies/design for X (DfX) must be offered to students. To design reliable products knowledge about modeling and simulation techniques is indispensable today. Advanced methods of computer aided design (CAD) and computer aided engineering (CAE), covering fundamentals like numeric/computational principles and use of software applications are an integrated part of advanced design education. It has to enable interested students to significantly enhance their skills regarding modern product development starting from requirements management over virtual validation of product properties to efficient documentation of the product and related processes. The concept of simultaneous engineering in the context of virtual product development has to be taught based on the introduction of tools like EDM/PDM, computer aided tolerancing or multiphysics simulation and according scientific fundamentals. Moreover specific skills in problem solving are advanced. Content related methods and skills like goal clarification, solution finding and information management are to be developed as well as process related methods of planning, evaluation, decision making and controlling, as illustrated in [9].

2.4 Soft skills

Apart from all subject-specific skills, methodological skills are also of interest, for example the abilities to manage time and to handle processes, to give precise reports and to give understandable and well structured oral presentations, furthermore the ability to use modern tools of information and communication technology and so on. Surprisingly, personal skills, for example reliability or sense of responsibility, and soft skills, e. g. social competences like the ability to work in interdisciplinary and more and more intercultural teams, the ability to handle conflicts or the ability to accept agreements, are evaluated as less important according to Figure 1, [5]. On the other hand professors and executive managers often complain of missing soft skills. Regarding this, more and more universities offer special courses covering these topics in addition to the main subjects. But these courses are mostly optional for students and not really integrated in the curricula.
Another interesting effect can be observed, watching alumni or young engineers in a typical workday: they mostly do not failure, because they do not know enough, but they are unaware of applying their knowledge. For example, another study of the Association of German Engineers VDI shows, that companies in 29% of all cases pay alumni off because they do not know applying their specific knowledge [10].

3 CURRICULUM FOR ENGINEERING DESIGN

The basics as well as some continuative aspects of engineering design and product development are already established fix in the three bachelor degree programs “Mechanical Engineering”, “Industrial Engineering“ and “Mechatronics”. Further special topics may be chosen in the bachelor programs to emboss a specific profile to engineering design. Of course, the most intensive education in engineering design is offered to the mechanical engineering students. Their curriculum is shown in Figure 2 and Figure 3. In the figures the following abbreviations are used: sem. = semester; CH = contact hours; L = lecture; PC = practical course; E = exercise; min = minutes. The highlighted courses will be described in detail later. The basics have a total amount of 22 contact hours (ch) respectively 27.5 ECTS. Even in the bachelor degree program, the subject-specific profile may be sharpened by additional 4…12 contact hours. The curriculum (basics) for the “Industrial Engineering” program is shown in Figure 4 and the curriculum (basics) for the “Mechatronics” program is shown in Figure 5. The special topics (Figure 3) may be chosen similar to the “Mechanical Engineering” program.
A characteristic of all courses is a high amount of practical work, so students directly have to apply their knowledge, which they get in lectures and exercises.At University Erlangen-Nuremberg engineering drawing is seen as a very important basis for all prospective engineers. Consequentially, engineering drawing is offered for all mentioned degree programs in the first two semesters in a total amount of 5 ECTS, respectively 4 contact hours as practical courses. Thereby, it is a philosophy at University Erlangen-Nuremberg, to cover the complete graphical representation of technical objects in the engineering drawing courses, ranging from technical drafts to a virtual product model. So, in the first semester (“Engineering Drawing I”), the basics of drafting, technical hand drawing and standardization are conveyed to students. All aspects are learnt using parts of a realistic and holistic

Basics

1st sem.	Engineering Drawing I (Basics)	2 ch L+PC
2nd sem.	Engineering Drawing II (Introduction in CAD)	2 ch L+PC
3rd sem.	Machine Elements I	4 ch L
	└ Short Practical Course	(90 min*)
	└ Exercises	2 ch E
	Practical Design Exercise I	2 ch PC
4th sem.	Machine Elements II	3 ch L
	└ Exercises	2 ch E
	Practical Design Exercise II	2 ch PC
5th sem.	Product Development and Design Project	4 ch L+PC

* optional

Figure 2. Engineering design curriculum for the mechanical engineering program (basics)

Special Topics

Upper semesters (≥ 5th semester)	— Compulsary elective courses —	
	Design for Production	4 ch L
	Methodical & Computer-Aided Design	4 ch L+E
	— Elective courses —	
	Integrated Product Development	4 ch L+E
	Modelling & Simulation in Product Development	2 ch L
	Tribology & Surface Technology	2 ch L
	Product Development with 3D-CAD-Systems	2 ch L+PC
	Innovation Methods	4 ch L
	Intellectual Property Rights	2 ch L
	— Practical courses —	
	Computer Aided Methods	2 ch L
	Process Simulation	2 ch L

Figure 3. Engineering design curriculum for the mechanical engineering program (special topics)

1st sem.	Engineering Drawing I (Basics)	2 ch L+PC
2nd sem.	Engineering Drawing II (Introduction in CAD)	2 ch L+PC
3rd sem.	Basics of Product Development	4 ch L
	└ Short Practical Course	(90 min*)
	└ Exercises	2 ch E
	Practical Design Exercise	2 ch PC

* optional

Figure 4. Basics of Engineering Design in the "Industrial Engineering" program

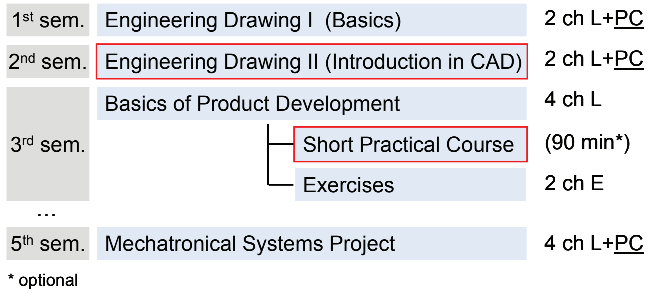

Figure 5. Basics of Engineering Design in the "Mechatronics" program

illustrating example, e. g. an industrial gear or a combustion engine. In the second semester ("Engineering Drawing II"), an introduction to computer aided design is given, also again for all three degree programs. Using modern midsize and high-end 3D-CAD-systems in a new form of "blended learning", the basics of 3D-modelling and of assembling are explained as well as using standard parts from libraries. Furthermore, the transfer of 3D-modells to proper technical drawings, which are conforming to drawing standards, is seen as an important aspect. See more to the CAD-education in chapter 4.1.

In parallel to these subjects, first lectures and exercises in engineering mechanics and engineering materials are offered, so it can be built on all these courses, when lectures and exercises in machine elements start in the third semester. Here, it is distinguished between the different degree programs the first time. Students of mechanical engineering get a more detailed insight of machine elements in a total amount of 11.25 ECTS, respectively 9 semester periods per week over two semesters as lectures and exercises. Students of industrial engineering and mechatronics get a shorter, function-orientated overview of machine parts in 6 contact hours lectures and exercises. See more to the machine elements education in chapter 4.3. In addition, students may take an optional practical course in machine elements, where they learn in small groups a lot of different design aspects (Design for Production, Design for Assembly) as well as function and form of machine elements by assembling and disassembling a realistic industrial gear. See more to this practical course in chapter 4.2.

Besides the mentioned lectures and exercises to machine elements, all students of mechanical engineering have to participate at two design exercises, which last over the whole semester (translated in 2.5 ECTS per semester). Two students have to manage a larger design problem self-dependent, but supported by a collegiate tutor and a scientific assistant. In this design exercises, students have to draft different possible design solutions, to calculate machine elements, to model complex machines in 3D-CAD and to create proper technical drawings. In this way, they can apply all their knowledge and skills, they have learnt in the previous semesters. Students of industrial engineering only have one of these described design exercises.

For students of mechanical engineering the basic education in engineering design ends in the 5th semester with a so called "product development and design project". Small groups of about 8-12 students have to manage a complex and realistic design problem – mostly motivated directly from industry – in a team-orientated project work. See more details in chapter 4.4.

In upper semesters, a lot of special topics to engineering design are offered as lectures, exercises and practical courses. Such are "Design for Production", "Methodical & Computer-Aided Design", "Integrated Product Development", "Modeling & Simulation in Product Development", "Product Development with 3D-CAD-Systems", "Computer-Aided Methods", "Process Simulation", "Innovation Methods", "Tribology & Surface Technology" or "Intellectual Property Rights", Figure 3.

4 SOME EXAMPLES OF REALIZATION

4.1 Engineering Drawing II (Introduction in Computer Aided Design)

Due to the transformation of the educational programs at University Erlangen-Nuremberg, new educational concepts in engineering design were established. In the 2nd semester – following the "traditional" engineering drawing course and preceding the design exercises, a new, self-contained course in Computer-Aided Design, called "Engineering Drawing II" was introduced. This course resembles the basis of all further computer related applied courses in the degree programs for mechanical engineering, industrial engineering and mechatronics. An overview of the applied CAx-technologies and educational objectives in the curriculum is outlined in Figure 6.

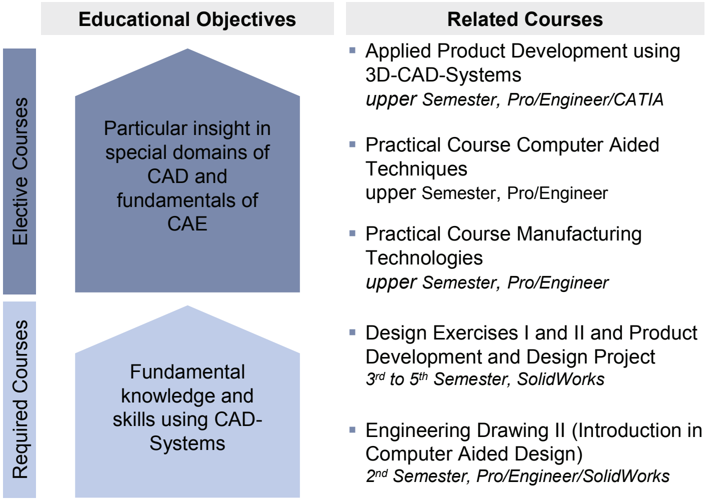

Figure 6. Educational objectives and related courses in CAD education

Whereas “Engineering Drawing II” and the design exercises focus on fundamental knowledge and skills using CAD-systems, advanced techniques and computer aided engineering modules are introduced in elective courses afterwards.

The course “Engineering Drawing II” is split up in two basic parts: a) the theoretical and practical courses supported by a scientific assistant and some collegiate tutors and b) practical exercises based on e-learning support. So a “blended learning” concept was chosen for this course using an e-learning platform for group management, sessions concerning CAD-basics and as download area for exercises. This approach *“enables a change of classical training to dynamic training networks”* [11], by use of e-learning system features like moderated forums. The course starts with a basic introduction to the fundamental principles of computer aided design. Among these fundamentals virtualization and CAD-specific concepts such as CAD-models, digital mock-up and functional digital mock-up are introduced. Also system architectures, product models and CAD-systems are discussed comparable to [11]. Moreover the importance of technical drawing practice and computer aided techniques is outlined: standards conforming product documentation, forms of technical drawings and bills of material are discussed referring to concepts of digital information processing available to improve economic efficiency. Finally CAD-systems, their modules and properties as well as modeling concepts are introduced. Simultaneously the fundamental terms like features, parametric modeling, associativity or parent-child-relations are defined and demonstrated using examples. For purposes of exam preparation this information is provided in lecture notes available form the e-learning platform. These basics are addressed in an e-learning module for homework, too, supplemented by a basic introduction into the CAD-Systems employed in the practical course and the exercises.

The practical course is set up of six sessions of about 90 minutes. At the beginning of each session the theoretic background of the course matter is outlined in brief. The students are confronted with a session specific task, Figure 7, and supported by handouts containing the approach and by assistants. The practical sessions are accompanied by five exercises for solution on a different CAD-System on home-computers. Therefore a campus program for usage of SolidWorks™ was initiated. So students are able on the one hand to repeat and transfer skills and approaches learnt in courses and to try out advanced issues. This process is guided by problem formulations available in the e-learning environment. The tasks contain elementary issues of solid modeling as well as alternative modeling techniques. The modeling strategy is systematically scrutinized by questions according to the e-learning lesson.

		Fundamentals		Advanced Strategies
		Practical Course	Practical Exercise (repetition)	Practical Exercise
Course Number	Demonstrator / Systems	Pro/Engineer	SolidWorks	Pro/Engineer or SolidWorks
1	Environment Handling		●	●
2	Part Input Shaft	●	●	
	Parts Input Shaft and Rib			●
3	Part Driving Cartridge	●	●	
	Part Upper Housing Flange			●
4	Assembly Driving Cartridge	●		
	Assembly Bearing			●
5	Technical Drawing Input Shaft	●	●	
6	Technical Drawing Industrial Gear 1	●		
	Technical Drawing Assembly Driving Cartridge 1			●
7	Technical Drawing Industrial Gear 2	●		
	Technical Drawing Assembly Driving Cartridge 2		●	●
	Online-Test		●	

Figure 7. Contents of the course Engineering Drawing II

The course matters concept is based on an industrial gear example (see Figure 8). It serves as a continuous illustration example for “Engineering Drawing I and II” as well as for the practical course machine elements. The first lesson covers basic environment handling of the applications Pro/ENGINEER™ and SolidWorks™ leading to the task of basic modeling of the axle driving shaft in lesson 2. The exercise focuses on different possibilities of modeling a rib. Revolved and extruded features are the basic features taught in the first lessons. They are supplemented by roundings and chamfers as well as tolerance and surface specifications. Lesson three focuses part modeling using patterns and symmetry employing the cartridge of the industrial gear. Modeling is finished by a lesson on building up assemblies according to its assembly sequence. As example the subassembly “driving cartridge” is chosen. The next sessions focus on the generation of proper technical drawings starting from page setup and labeling field. First of all a manufacturing drawing is to be created based on an associated CAD model of the axle driving shaft. All required views, details, cross sections, dimensions, tolerances and surface specifications have to be created. The last two sessions focus on the generation of a technical drawing of a complex assembly (subassembly for homework). The extraction of the views based on a complex assembly is accompanied by generation of details, cross sections and a bill of material with dedicated balloons. The course is finished by an online test using the e-learning platform focusing the different aspects of computer aided design. The questions deal with modeling strategies, important definitions of technical terms and transfer questions related to topics addressed in the lessons and the lecture notes. The e-learning system therefore supplies services for administration, communication, instructional and subject-specific contents, assessment and management of the course.

4.2 Practical Course Machine Elements

In addition to lecture and exercise of Machine Elements I and II and the design exercises mentioned above an optional practical course is offered for all interested students. Objective of the course is to experience different technical components and machine elements by being able to handle them oneself. So students get to understand the function as well as basic aspects of manufacturing and assembling. Moreover reading of technical drawings by identifying components of the gear should be enhanced. Small groups of about six students are invited to pass a hands-on lecture. As illustration example the industrial gear example mentioned above is used. It resembles a realistic gear but due to didactic reasons some technical and economical aspects have been disregarded. It is used only for purposes of demonstration and education. The industrial gear has a power of 2 kW and a driving torque of 6.4 Nm at an input speed of 3000 rpm. The transmission ratio of 9.12 is realized by three gear pairs. The main dimensions are (height x width x depth) 254 mm x 445 mm x 238 mm. A digital mock-up and a complete technical documentation as well as three physical mock-ups exist, Figure 8.

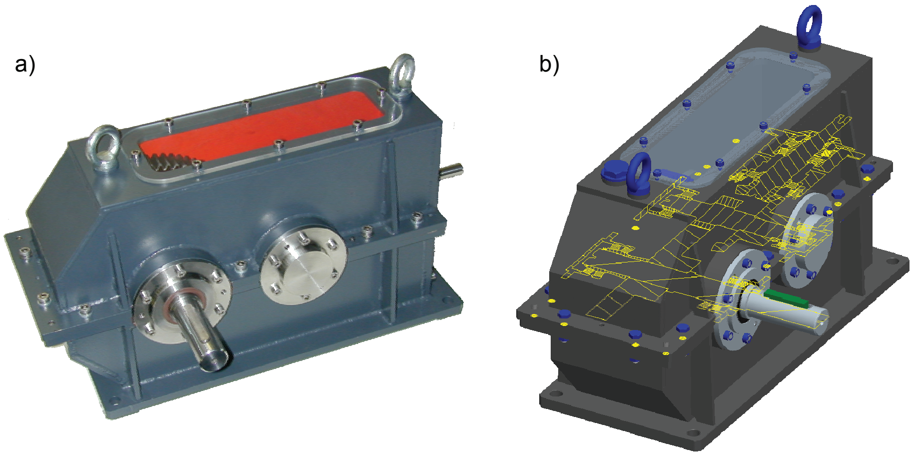

Figure 8. a) Physical and b) virtual digital mock-up of the industrial gear

The gear is employed to demonstrate the basic function of pinions: a skidding-free transfer of movement and mechanical performance as well as a conversion of torque and speed in a fixed ratio. Moreover the spur gear and pinion pairings such as wheels or bevel, or worm gear pairs with involute gearing, the types of archery gear teeth, straight toothing, and zero gearing can be explained briefly. The transmission efficiency can be explained by the demonstrator and tribological aspects will be discussed. In addition, the design of turning parts and aspects of the mechanics of materials of the shafts can be shown: heels, slots, center holes and tolerances are explained based on the components and assemblies. Moreover fit-in key connections, interference key connections and spline-shaft-connestions can be tested using the relevant subassemblies. One of the most important aspects is to point the bearing arrangement and their function up. This results in explanations of the distribution of forces in shafts, casings and covers. In addition miscellaneous materials are available in the industrial gear whereas their different properties and functions are highlighted in the course. Some of the most important machine elements like fit-in keys, screws of different types, bearings, grooved nuts, retaining rings or different types of sealing are available for demonstration and assembly. Finally welding and appropriate forming design can be introduced using the casing.
This lesson serves as a motivation-basis for the upcoming lectures and exercises and is therefore performed at the beginning of the lectures of Machine Elements I and II. Moreover students are able to perform teamwork disassembling or assembling some of the industrial gear components. So, fundamental skills and knowledge (see chapter 2) are taught in a practical way.

4.3 Machine Elements I and II

In 1997, a group of German professors, organized in the German scientific society for machine elements, engineering design and product development – WGMK – formulated the so called “Heiligenberger Manifest”. In this paper modern education of machine elements was sketched [12]. According to this, the main objective of this educational approach is imparting machine elements in a system-orientated and function-orientated manner. The education in machine elements at University Erlangen-Nuremberg follows this concept consequently. It is given a function-orientated overview of all existing machine elements. Furthermore, the required combination of bottom-up- and top-down-approach designing complex technical systems based on machine parts as smallest elements is taught. Here, it is differed between the design *of* machine elements and the design *with* machine elements. Important machine elements are discussed more detailed concerning function and functionality, characteristics, calculation, design, realization and usage. Function and calculation of machine elements is traced back to the basics of engineering mechanics (in particular statics and dynamics), strength of materials (existing stresses and sustaining stresses) and tribology (in particular friction and wear). The lecture is supplemented by exercises. Additional exercises with detailed solutions to each machine elements are offered to the students in printed form, for preparing tests or delving skills. In parallel, students have to apply their knowledge and skills in design exercises, as mentioned above.

4.4 Product Development and Design Project

Concerning boundary conditions mentioned in chapter 2, the department of mechanical engineering of University Erlangen-Nuremberg has decided, to establish an *obligatory* course in the 5th semester for the mechanical engineering program, in which students should learn and activate methodological and social skills *in combination* with applying their subject-specific knowledge in a realistic environment as possible. This course is focused on the subjects of product development and design, but also cross-linked to other important subjects, especially to the field of production. The department of mechanical engineering of University Erlangen-Nuremberg has experience in such design projects for mechanical engineers since 1998 but within the restructuring from the Diplom to the bachelor program, this former course was optimized and intensified.

The course is organized in a way comparable to classical case studies but enhanced with some *integrated* seminars to special topics, in particular teamwork, project management, rhetoric respectively presentation techniques and design methods. These seminars are done by special coaches in the course of the semester, so students may apply these skills immediately in the project. All students get a complex design problem, in general motivated by or in co-operation with an industrial partner. Since students already have heard all basics, in particular engineering mechanics, machine elements and production technology, but also thermodynamics, fluid dynamics or metrology, for example, nearly all aspects of mechanical engineering may be integrated in the design problem. Sometimes, one ore two lectures are given, so that students learn more about backgrounds of the specific application, following [4]. Typical problems of the last years are shown in Figure 9.

Figure 9: Examples for former design projects and typical students' solutions. Left side: a coining machine; in the middle: a wire dereeler; right side: multiphase screw pump

The problem for itself is described in an abstract and neutral way, whereas the relevant requirements are defined in a standardized requirements list. Furthermore, realistic boundary conditions and restrictions are given, for example possibilities of production facilities, human resources and so on. Based on this information, students go through a nearly complete product development process, beginning in the late planning stage but including conceptual design, embodiment design and detailed design. They perhaps have to complete the requirements list, to search for ideas and solutions, to draft concepts, to calculate parts and to provide functionality, perhaps to discuss with suppliers, last to model the whole machine and to create proper technical drawings. So students are *"encouraged to develop their own problem statements, explore a range of potential solutions and navigate through the hurdles that may arise in the process"* as proposed in [8], *"rather than being provided with idealized problems and 'perfect' solutions"*.

The problem has to be solved in small teams of about 8 students. These teams have to be self-organized but defining a team leader. The work has to be organized as a project, so defining milestones, periodically reporting of results and calculating working time and personal costs are obligatory. Each team is managed by a scientific assistant and supported by a collegiate tutor. Every team has the possibility to use well equipped rooms for collaborative work, discussions or team meetings. These rooms are denoted as "house of project". They are equipped with some PCs, where different CAD-, CAE-, and CAI-software are installed, furthermore flipcharts, whiteboards and so on. In addition they can use a common VR-lab, including a power-wall, optional with haptic-interface and a rapid-prototyping-printer to check and validate CAD-models in a fast way or to discuss design solutions with scientific assistants or master craftsmen from the production department of the University. Of course they also have the possibility to use the common CAD-lab of the department for 3D-modeling or plotting drawings.
At the end of the whole project, students have to hand complete product documentation over to the scientific assistant. Furthermore, the best teams have to present their results to the industrial partner and get the possibility for an excursion. Very good solutions may be advanced within one or more bachelor thesis.

5 COMPARISON BETWEEN EDUCATIONAL PROGRAMS OF OTHER GERMAN UNIVERSITIES

A comparison of the percentage of design education basics in bachelor programs at German universities reveals that Erlangen (E) is a kind of front runner: a plenty of contact hours in basics engineering design education is spent. The credit point percentage is about 15% compared to a mean of 12.5%.

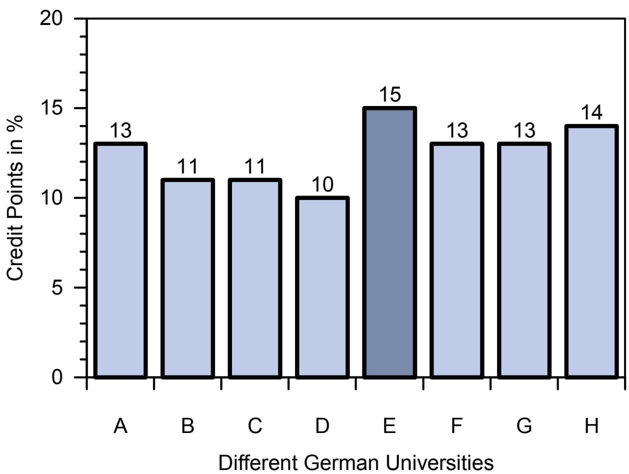

Figure 10: Comparison of credit points between different German universities

This weight is not based on a historic development. The department of mechanical engineering in Erlangen originated from manufacturing technology and is now offering three educational programs: Mechanical Engineering, Industrial Engineering and Mechatronics in cooperation with other departments. The close relationship, a broad acceptance and the awareness of interdependencies with these other divisions lead to the emphasis of engineering design in supplementation to fundamental skills and knowledge of mechanics, manufacturing and assembly technologies and materials science for example.
At other German universities, for example engineering drawing is skipped and the program schedules working on CAD-Systems from the very beginning. This seems to be a very contemporary approach but our experience revealed that the complexity of the CAD-system distracts from the basic aim: to convey the skill to be able to review designs and use an efficient tool for sketching technical ideas in a manner a third one can understand quickly and unambiguously.

Moreover the proposed program focuses much more on teamwork as known by the authors than on other universities. Teams of two students and of up to eight students as well allow to develop skills and gain experience in small and diverse, dynamic groups. A close contact to scientific assistants also simulates a kind of compartment.

6 SUMMARY AND OUTLOOK

Due to the reformation of German education programs, new concepts of education in engineering design were established in different engineering programs at University Erlangen-Nuremberg, especially in the traditional mechanical engineering program. The education in engineering design can be characterized by a stringent structure in the bachelor as well as in the master programs, by a high degree of cross-linkage to other engineering disciplines, such as engineering mechanics or production technology and by modern concepts of imparting subject-specific knowledge in combination with soft skills. Furthermore, an important characteristic is a high amount of practical courses – compared to other universities (section 5) –, where students directly have to apply their knowledge and skills. Some examples of realization were presented, in particular the courses “Engineering Drawing II (Introduction in CAD)” and “Product Development and Design Project”. In the first mentioned course, a modern way of computer-supported, “blended learning” was realized. In the second mentioned course, new ground was broken by applying subject-specific knowledge in combination with soft skills by offering an obligatory project already in the bachelor program. These steps have to be seen as an evolutionary development of former courses and as an optimization of education in engineering design, regarding demands to product developers and engineering designers today and in future.

In the moment, the first generation of bachelor students passes these new courses. First feedback was quite positive, but certainly, it is too early, to evaluate the new educational concept in detail. As stated in [4] curricula changes require a period of stability in order to evaluate their effect. Base of all these courses have to be well equipped rooms and labs, a factor, which was not always fulfilled in the last semesters. But at University Erlangen-Nuremberg joint efforts were taken to enhance this situation until end of the year 2009. We are going to report our experiences and results of evaluations at the next ICED conference in 2011. At this point we want to say thanks to the colleagues at the department of mechanical engineering at University Erlangen-Nuremberg for having a great understanding of the importance of engineering design and product development and their encouragement designing a sophisticated and stringent curriculum.

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