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Competence-profile oriented education with the Karlsruhe Education Model for Product Development (KaLeP)

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ABSTRACT: The development of products is one of the most complex and important stages in the value creation chain. Besides disciplinary competence and competence in methods, key abilities like social competence, as well as the capability to make and realise decisions, are considered essential for future engineers to launch successful products in the market. The basis for the Karlsruhe Education Model for Product Development (KaLeP), which started in 1999, is the holistic understanding of product development. For an education oriented on the demand of later professionals, the courses are divided into three parts: theoretical knowledge imparted in lectures, tutorials where students work with practical applications of this knowledge and the implementation of this knowledge in a workshop with a complex project. The courses are embedded in a realistic and industry-like development environment. The KaLep is part of an integrated education that is closely associated with materials science, manufacturing technology, engineering mechanics, etc. To ensure a methodical development, the KaLep is separated into three education stages that are characterised through different fields of product development-specific knowledge, namely: systems, methods and processes.

INTRODUCTION

The industrial environment that new university graduates encounter is characterised by highly dynamic and enormous complexity. A very important aspect is multidisciplinary product development. The combination of classical mechanical design education with computer sciences and mechatronics requires a high degree of candidness and methodical progression. Further, the integration of key abilities in education is necessary.

The Institute for Product Development (IPEK at the University of Karlsruhe in Karlsruhe, Germany) has developed an education model that combines these main aspects – the Karlsruhe Education Model for Product Development (KaLeP). In the domain of product development, it is essential to work on concrete examples with transferability to other cases. Students cannot learn product design in the first semester, but it is important for the motivation of students in the early stages of their studies. This education must be executed in a step-by-step manner. Conceiving, designing, implementing and operating are aspects that together represent a methodical process and bring together essential *milestones* of product development [1]. The IPEK deploys these aspects in the course, *Integrated Product Development*.

THE RELEVANCE OF KEY ABILITIES

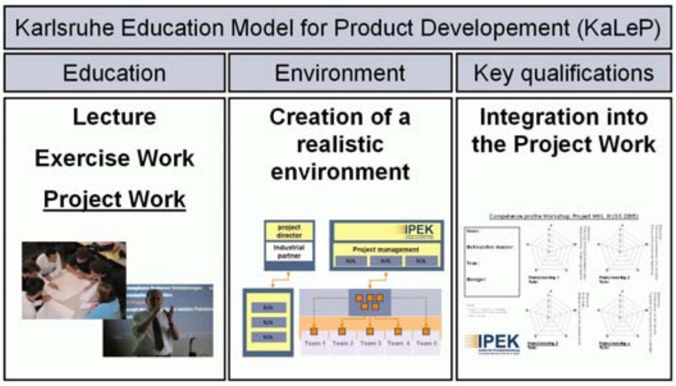
During the job application process, engineers concentrate on explaining their disciplinary competences. Key qualifications are often positioned in the background [2]. A VDI (Association of German engineers) study shows this problem clearly: for 55% of job entrants, the reasons for detachment are social skills (multi-nomination was possible) [3]. Thus, an exposure to these skills is necessary. Students must learn how important to the success of a project a systematic proceeding is and the proper method for learning about this issue is for students to learn about it in lectures, as well as experience it. These experiences must be collected in concrete project work and not in special *soft-skill* courses – soft skills must be learned while working on the project so that the important aspects of self-organisation, teamwork and methodical process can be integrated in product development education. An overview of the skills that should be included in the curriculum are displayed in the *Conceive – Design – Implement – Operate* (CDIO) syllabus [4]. These key skills are particularly important in multidisciplinary product development education.

Working on a multidisciplinary project requires a high degree of teamwork, plus time and project-management skills due to differences in the types of thinking and approaches to problem solving that engineers of other disciplines have.

THE KARLSRUHE EDUCATION MODEL FOR PRODUCT DEVELOPMENT

This holistic understanding of product development requires a holistic education model. The Karlsruhe Education Model of Product Development (KaLeP), which was introduced in 1999, combines many of the main aspects for product development. The basis for the KaLeP are its three columns (see Figure 1), ie education, environment and key qualifications.

The important aspect is that these three columns work closely together. Students' education is divided into three parts. The theoretical knowledge is imparted in the lecture by an ex-cathedra teaching format. In tutorials, students use this knowledge in practical applications by solving various problems, eg analysing technical systems, etc. The implementation of this knowledge takes place in the workshop. Teams of five or six students work together on a complex project task. The KaLeP is based on a constructivist learning process whereby students must construct their knowledge for themselves in order to understand it correctly [5].



Karlsruhe Education Model for Product Developement (KaLeP)		
Education	Environment	Key qualifications
Lecture Exercise Work Project Work	Creation of a realistic environment	Integration into the Project Work

Figure 1: The three columns of the KaLeP.

Education is integrated in a realistic and industry-type of development environment. The reason for this is to motivate students and confront them with industry processes, eg leadership and management systems. The KaLeP is part of an integrated engineering education at the University of Karlsruhe (TH), which is closely associated with materials science, manufacturing technology, engineering mechanics, etc.

A THINKING MODEL NOT ONLY FOR EDUCATION – C&CM

Because of the variety of different industrial sectors, mechanical design education is a very complex issue. After graduation, students should be able to adapt their knowledge to solve special problems in their industrial environment. To teach this holistically, the KaLeP is based on a methodical and structured process. In order to realise this, the IPEK integrates a theory for abstract technical systems. This theory is a thinking model called the *Contact & Channel Model* (C&CM) [6]. This model is simple to use since only three hypotheses form its basis. One of them is that every technical function is fulfilled by contact with at least two elements: the Working Surface Pairs (WSP), as well as the structures linking them: the Channel and Support Structures (CSS).

Based on practical experience, there are many methods built on the C&CM. There are design rules and methods to analyse whole product architectures. Figure 2 shows a simple example for the abstraction of a crane with the C&CM. The model is not restricted to mechanical systems; electrical systems and systems based on information technologies can be displayed too. Because of its broad application area and its ease of use, it is very powerful in engineering education.

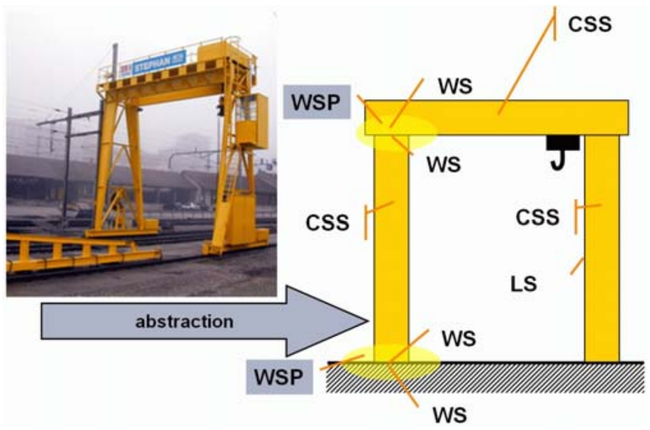


Figure 2: A simple example for the abstraction with C&CM.

With the C&CM, selected machine parts are imparted to students in great detail in lectures. After having understood this model, they are able to better analyse the function of different unknown machine parts and systems. Further, the C&CM allows the analysis and synthesis of systems. This is very important for constructive tasks, such as in the workshop or the industrial environment. Neither an overview nor special examples of parts and systems are sufficient. An abstraction and general description of technical systems is the key to effective engineering education since the variety and complexity in the technical sector is permanently increasing.

To evaluate the use of the C&CM, a reference task was created to determine the student's ability to abstract and analyse an unknown technical system. It consists of questions that allow conclusions to be drawn about the student's way of thinking. A great number of students are unfamiliar with the system prior to the task. Through methodical progress and the utilisation of the C&CM, they learn more about the system and many students can completely describe the function of the system at the end of the task. The results are impressive. Since the introduction of the KaLeP with the embedded C&CM, the number of students who could identify the function of the technical system has significantly increased.

THREE STAGES OF THE KALEP

Design-build experiences are fundamental to motivate students. They are structured and sequenced to promote early success in engineering practice. Furthermore, they provide a solid foundation upon which to build deeper conceptual understanding of disciplinary skills [4]. The KaLeP integrates such design-build experiences on two levels: by splitting product development education into three stages, a methodical process is achieved. This is oriented towards certain fields of product development-specific knowledge: systems, methods and processes (see Figure 3). In mechanical design, there are simpler systems included, eg in IP, students handle very complex design-build projects during the product development process through to the prototype.

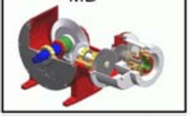
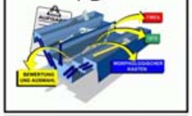
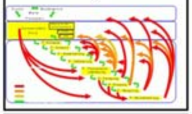
	Systems	Methods	Processes
Education	MD 	PD 	IP 
Rate key qual.	high	medium	very high
Topics key qual.	▪ teamwork ▪ self-organization ▪ articulation and communication ▪ elaboration potential	▪ method knowledge ▪ creativity technics	▪ team-leading ▪ team-development ▪ project-management ▪ presentation / communication ▪ self-management
number	800 students	400 students	30 students

Figure 3: Systems, methods and processes in the KaLeP.

STAGE 1: MECHANICAL DESIGN I, II AND III

The first stage, Mechanical Design (MD), is placed in the first two years of study accounting for a large number of students (about 800). Concrete systems are implemented to gain clarity and reference to practice the fundamentals of MD. Here it is particularly important to motivate students and arrange the curriculum to include demonstrations. To achieve this, the KaLeP integrates a second design-build sequence at the MD level.

Mechanical Design I: the Transmission Workshop

Students are organised into about 160 groups. Each group receives a gearbox and appropriate tools. In addition to lectures and tutorials, different tasks must be handled in the workshop. This starts with a simple disassembly and assembly of the whole gearbox, when functional and relevant working surfaces must also be analysed and described. At the next meeting, students prepare technical drawings and free hand drafts. Tutors discuss achievements of the groups. Here, the C&CM plays a central role. The main functions of gear wheels, bearings and screws are known by most students, but knowledge about distance rings and fits is less common. By analysing the working surface pairs, and channel and support structures, students' awareness of the existence and function of various parts grows.

Mechanical Design II: Simple Constructive Tasks

In MD II (third semester) the main focus is no longer on an analysis of technical systems, but on the synthesis. Lectures and tutorials include principles of design, tooth systems, dimensioning, etc. In the workshops, students solve constructive tasks beginning with simple bearings to a complex angular gear. The results are presented to the tutor at certain milestones and new tasks are defined.

Mechanical Design III: Development of a Complex System

In the fourth semester in MD III, students must develop a complex system. Teamwork is essential to accomplish this. Because of the extensive task, work must be unitised and each team member has his/her own division and must work in cooperation with the others. Previous tasks have included a ball bearing assembling machine and a carousel placed on a car trailer. Figure 4 shows an overview of MD education.

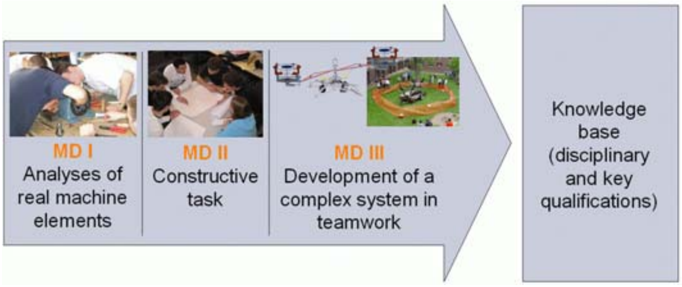


Figure 4: MD education as methodical process.

After finishing MD education, an examination is held that is split into the theoretical and practical parts. Students are given a very complex constructive task, which demands a structured process, creativity and time management to solve the task within three hours – all aspects that they have learned in the workshop in addition to disciplinary competences.

STAGE 2: PRODUCT DESIGN

The course *Product Design* is a conjunction of MD and Integrated Product Development. In the industrial environment, engineers often only know that development methods exist, but do not use them because they do not know how they work or think that too much time is required for little return.

At this point, *Product Design* is presented. Starting with the basics of the product development process and product neutral methods, the students get an overview which methods do exist, which methods are to be applied in a particular situation and how to use them. It is important that Product Design is split up into the areas of development methods, manufacturing techniques and materials science while maintaining a high degree of interaction between these three domains.

STAGE 3: INTEGRATED PRODUCT DEVELOPMENT

The third phase consists of the course *Integrated Product Development.* A complete product development process through the prototype phase is completed in close cooperation with an industry partner. Because of the very high degree of supervision, only select students can take part in this course. At the start of the course, an industrial environment and development concept is created in cooperation with the partner. The development tasks are deliberately formulated to be very broad.

As described in CDIO Standard 6, the physical learning environment (consisting of learning spaces, seminar rooms, laboratories, workspaces, etc) is a fundamental resource to learn the process of designing, building and testing products and systems [4]. Each team gets its own office with facilities (ie CAD-computer, telephone, utilities for creativity sessions, etc). They also have opportunities to use modern equipment like a videoconference system, smartboard, etc, in the multimedia room of the IPEK. Prototypes can be manufactured in the mechanical workshop. The structure of the project in which the teams are placed is shown in Figure 6. Additional students take part in lectures and a workshop where they deepen their knowledge about the development processes of enterprises, systematic planning and controlling, and the practical adoption of complex creativity methods, presentation techniques, etc.

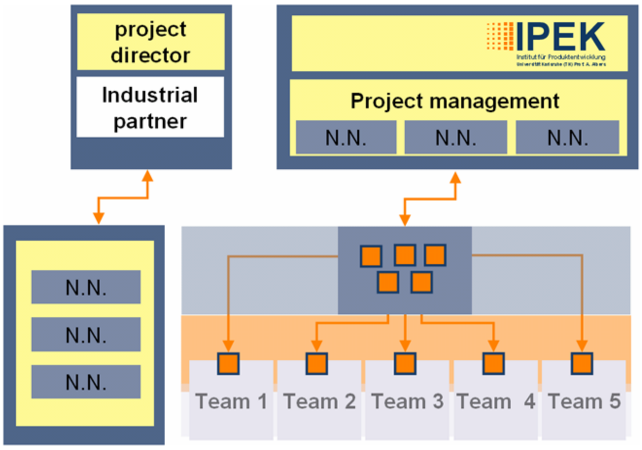


Figure 6: Environment and structure of IP [7].

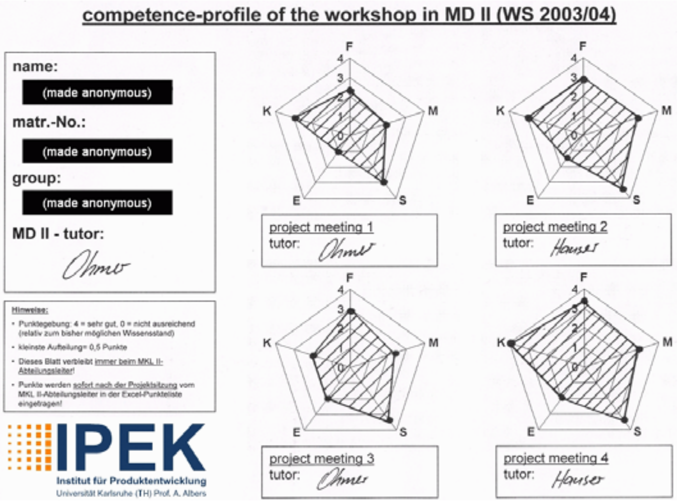
The first step for the IP teams is to create a project plan with concrete tasks and milestones. Due to the broadly formulated task, students next use market analysis, scenario analysis, etc, to define their product profile. In the first presentation, students and project management discuss the product profiles. Then the development of concrete ideas and concepts for the product begins. A competitive environment is created between students and thus each team develops a unique product. After two other presentations (the concept presentation and a spontaneous presentation), the final presentation is given before many industrial representatives. Here, students demonstrate their prototypes and deliver the project documentation to the project partner. A product developed in cooperation with the STIHL Company had its market entry on 1 January 2006. Patents have been applied for many other products. Thus, a win-win situation is created for students, industry and the IPEK.

EVALUATION

By means of an online evaluation system, it is possible to react quickly to students' statements during the semester. In order to give students a feeling of the importance of key qualifications, the IPEK has created a special questionnaire consisting of two parts. First, students must estimate how important the different key qualifications are for the engineer generally. They have to evaluate their own knowledge and skills in this area. It is possible to compare the tutor's estimation with students' estimation. The administration has the ability to change the focal points of the programme if needed. Another aspect is the evaluation of alumni. Processes are optimised by analysing how important several competences are in the professional world.

In addition to the online evaluation system, the IPEK uses the *competence spider* (see Figure 5). After each workshop meeting, eg in MD, students are evaluated concerning four different competences and a potential, as follows:

- F: disciplinary competence (basic knowledge, machine parts, foreign language, etc);
- M: methodological competence (development methods, FMEA, QFD, CAD, etc);
- S: social competence (communication, teamwork, leadership, presentation);
- K: creativity competence (problem sensitivity, creativity techniques, courage for new solutions, etc);
- E: elaboration potential (power to put something into practice, cost awareness, systematic work style, etc).



competence-profile of the workshop in MD II (WS 2003/04)

name:
(made anonymous)
matr.-No.:
(made anonymous)
group:
(made anonymous)
MD II - tutor: Ohmer

Hinweise:
- Punktegebung: 4 = sehr gut, 0 = nicht ausreichend (relativ zum bisher möglichen Wissensstand)
- kleinste Aufteilung= 0,5 Punkte
- Dieses Blatt verbleibt immer beim MKL II-Abteilungsleiter!
- Punkte werden sofort nach der Projektsitzung vom MKL II-Abteilungsleiter in der Excel-Punkteliste eingetragen!

project meeting 1
tutor: Ohmer

project meeting 2
tutor: Hauser

project meeting 3
tutor: Ohmer

project meeting 4
tutor: Hauser

Figure 5: Evaluation using the *competence spider*.

Students are also integrated in the evaluation process. Team members have the possibility to evaluate each other. After a discussion, the tutor fills in the competence spider. Students thus learn to review other work in relation to their own performance.

To ensure consistency and fairness, the different competences and potential are clearly defined and a guide is given to tutors that describes the grading of the points, eg the elaboration potential is discussed in more detail. This very important potential is characterised by the following properties:

- Power to put something into practice;
- Power to reach a decision;
- Cost awareness and customer orientation;
- Systematic work style;
- Requirements oriented;
- Exposure to emergency situations and frustration tolerance.

The grading of the points is listed as follows:

- 0 points: resigned from difficulties, aims not reached;
- 1 point: partially resigned from difficulties, aims reached incompletely;
- 2 points: difficulties negotiated, aims reached;
- 3 points: difficulties negotiated well, aims reached completely;
- 4 points: difficulties negotiated without problems, aims outreached.

Such a description exists for each competence and each potential to ensure consistency.

CONCLUSIONS

Looking retrospectively over the last 10 years, the IPEK can say that it is on the right track concerning engineering education. Feedback from industry and alumni clearly proves this development. Today, many companies advance the opinion that key qualifications are a very weak point of entrants in addition to methodology and systematic processes.

Because of this, the KaLeP must be optimised and accommodated permanently. In 1999, the IPEK recognised the situation and *conceived* a concept. After that, the KaLeP was *designed* and *implemented* in education. Now it is time to *operate* in order to fine-tune the model so that the Institute for Product Development can offer this education to students in the future.

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