“The Karlsruhe Model”- A Successful Approach to an Academic Education in Industrial Product Development

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1 ABSTRACT

The increasing complexity of product requirements combined with a customer tendency to prefer more simple and profitable solutions needs the integrated use by the design engineers of targeted combinations of organisational, technical and systematic tools based on an holistic view of the entire product development process. The education of design engineers has to react to these new professional requirements and excellence in professional competence must be generated. The education of mechanical engineering students in machine design can make a decisive contribution in obtaining technique and social competence for later success in study and profession.

At the University of Karlsruhe the Institute of Machine Design and Automotive Engineering has constituted the new education concept called “The Karlsruher Model” in order to take up these challenges. This paper will present the basic course content and methodological approach and will describe our initial experiences with this new educational concept.

2 INTRODUCTION AND MOTIVATION

Successful product development leads to competitive products and safeguards both the existing and future market position of an industrial concern. The present market situation can be described as having

- Short product life cycles
- Lower price expectation for even higher standards of quality
- Growing requirement for more specialised products
- Short product launch cycles

The conditions for a successful product under these demands is a complete holistic view of the total development process from market demand to product launch described with the term **“Integrated Product Development”**. This development philosophy is based fundamentally on the creation of multi-disciplined project teams with the ability to quickly adapt to the step changes in a dynamic marketplace and possible fundamental changes in base technologies. This requires all the members of the development team to personally identify with the development process and to be organised so that all relevant data is to hand. Therefore new requirements are growing up for qualification, particularly to the combination and the weight of competence by design engineers (Fig.1). Required is an outstandingly creative and flexible engineer, able to think about the task “in the round” and fitted out with management skills – a specialist with the ability to act as a successful generalist. Competence in the fundamental technologies, social interaction, and design techniques are the essential core qualifications of a design engineer which up to now have not been taught in a traditional university curriculum in the broadness required. The university education of design engineers has to react to these new professional requirements and an adequate professional competence must be generated [99/14].

3 EDUCATION OBJECTIVES

The education objectives can be structured as follows according to the core competencies required for development engineers:

3.1 Competence in Fundamentals

The traditional university education provides a broad fundamental engineering knowledge and offers discipline specialisations. The limits of these specialisations must be reconsidered and varied, where necessary, to achieve an integrated process of development. For the development engineer it is necessary to consider technical, economic and organisational systems in terms of the complexity of the product, heterogeneity of product components (mechanical, electronic, hydraulic, data processing etc.) and their combination into a superior marketable product.

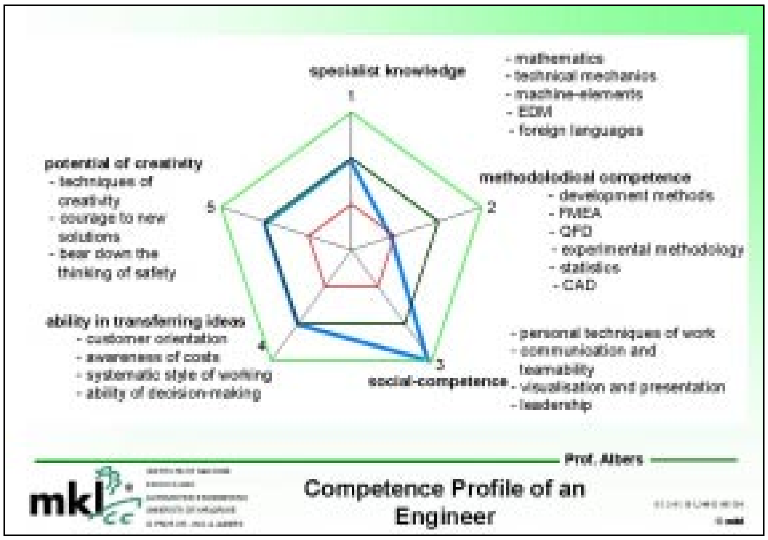

Figure 1: Competence Profile

The ability to analyse problems, develop solutions, operate work stations and processes is an essential part of the competence in fundamentals. The continuous updating of information about development, relevant materials and components from trends in market and research requires an efficient strategy for information procurement, data processing and the readiness for a Life-Long-Learning even beyond all "Comfort Zones" of individual specialisations. The split between a product specific specialisation on the one hand and the integrated development process on the other hand requires an efficient management. Internal processes regarding information, planning, decision making and execution are to be co-ordinated in order to avoid loss of time, misunderstandings and errors which can appear across specialisation interfaces. This management task is not the job of the project manager by himself but part of the working process of the whole team [99/9].

The following educational objectives have been derived from competence demands outlined above at the Institute of Machine Design and Automotive Engineering. They are developed to teach the following ways of thinking and their correlation:

- *Process thinking* - Product development as a process chain
- *System thinking* - Product development as a systematic process
- *Innovative thinking* - Product development as an innovative process
- *Problem thinking* - Product development as a problem solving process
- *Integration thinking* - Product development as an integrated process

- *Organisation thinking* - Product development as a management process
- *Cost thinking* - Product development as a cost optimised process
- *Time thinking* - Product development as a time optimised process
- *Customer-/Quality thinking* - Product development as a customer-oriented process
- *Market Thinking* - Product development as a market-oriented process

3.2 Social Competence

A successful integrated product design is based on a goal-oriented and innovative culture of dialogue in enterprises with the following kinds:

- *Problem-solving culture*: Seeing problems as a chance and challenge to think of possibilities instead of difficulties
- *Constructive error culture*: Solving conflicts co-operatively, analysing causes, initiating perspective variation
- *Creative culture*: Promoting flexibility in thinking, creating bases for cross-functional thinking, imagination, creativity and inventive chaos
- *Fractal culture*: Employees as responsible, self-controlling, closed-loop control systems in the product development process
- *Courage-of-conviction culture*: Promoting constructive obstinacy and courage of conviction, breaking moral cowardliness and hasty uncritical acceptance.
- *Comfort Zone culture*: Application of the employees in accordance with their talents and interests, promoting fun

A distinct communication behaviour of employees is necessary for a dialogue culture described above. Decisive here is the outwardly directed behaviour of the participants in co-operation with other colleagues involved in the development process. The educational objectives which cover all these requirements are:

- Communication ability
- Co-operation ability
- Ability to resolve conflicts

3.3 Methodological competence

The Institute of Machine Design and Automotive Engineering defines “method” in this context as tools required for the technically and socially competent development engineer to convert steps of the product development process into real concrete progress in the generation of a target product. The support of these tools to translate the product idea from the product concept and -design to product manufacturing and recycling is an important requirement for an efficient treatment of the development processes [99/5].

Therefore the following education goals are defined by the Institute:

- Teaching approved techniques compatible with each process step of the product development process
- Teaching criteria to select efficient techniques
- Teaching application experience and safety

4 CONVERSION OF EDUCATIONAL GOALS

The education model is based on the following structures (Fig.2):

Basic courses **MKL** (Maschinenkonstruktionslehre I-III) and the graduated course Integrated Product Development **IP** (“Integrierte Produktentwicklung).

5 MKL

The lecture is fundamentally understood as a superordinate element of the teaching model and offers the basics for the other two modules of the doctrine. It explains the product development process by using examples from the industrial development practice. Two guiding examples are important here: the drive-line of a car and an extruder. Both ones accompany the entire lecture and the discussion of special machine-elements.

The **exercise** deepens the theoretical knowledge and shows how to use it in practice. Special elements of the exercise have to be processed within the framework of the third module of this teaching model: the workshop. In the **workshop** student teams work on concrete practical tasks. At the beginning of this event, the emphasis is the practical understanding of machine-elements by the students. The workshop shows special construction-elements and -systems which guide through the whole event and which are already completely known in function and design by the students.

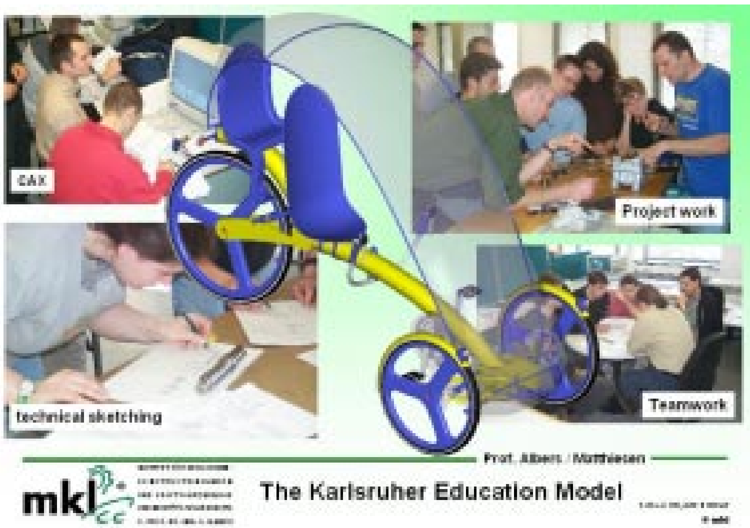

Fig. 2: The Karlsruhe Education Model

5.1 Lecture

Traditional lecture-concepts offer a sequential presentation of different machine-elements. Those lectures are an attempt to handle all machine-elements completely. The function, the design and the layout of each machine-element is exactly described. Nowadays a complete treatment of all existing machine-elements is not possible and efficient any more. The main reason for this is the increasing number of new machine-elements while having a constant capacity of time to impart the lecture. The new Karlsruhe-lecture-concept is based on a completely different view. Its main aim is to communicate an overall and complete science of machine-elements in spite of the increasing number of machine-elements.

Machine-elements are now considered to be on a higher level of abstraction. By this they can be handled with the modern tools of design-methodology. Most machine elements can be understood as a system of several components. In this case, every element of a system fulfils a function with the help of one or several contacts to another system component. The actual function and therefore the desired effect is implemented by the contact of one surface with another. Consequently these surfaces become functional surfaces.

To fulfil the function of the machine-element every functional surface is in contact with another at some time. Those two functional surfaces form an **working surface pair** (wsp). Strain, construction and design of these functional surfaces depend on the function of the machine element, the marginal demands and the contacted functional surfaces. Wsp‘s of completely different machine elements are often designed in the same way because the same elemental functions are realised by them. An example for such an elementary function is the lubricated contact under Hertzian stress. A task of the further structure of the machine-element is to keep the functional surface in its defined position. Therefore it is called **channel and**

support structure and has to be designed in accordance to its functional performance. Similar to the functional surface the layout and design of the supporting structure depends on the function of the machine-element and the surrounding demands.

At the beginning of this new lecture-system the students are confronted with the theory of the **working surface pairs** and **channel and support structures**. By this machine-elements are put onto a high level of abstraction already at the beginning of the studies. At the same time the ability to think in an abstract way is taught and deepened. This skill is very important for the future mechanical engineer. During the further process the theory will be explained on the basis of selected machine-elements examples. The aim is to teach the ability to apply the abstract theory on concrete examples. At first the machine-elements are regarded from the viewpoint of the guiding system. The next step is the discussion of their elemental characteristics and their interactions within the entire system. A special example in this context is the disc spring as an element of an automobile-clutch. The parallel discussion of aspects of design, manufacturing, cost and dimensioning and the explanation on practical examples leads to an entire view and comprehension. Corresponding to this the emphasis of the lecture differs from the topics of conventional textbooks on the science of machine-elements. They are the basis for further learning of factual knowledge during private studies. While discussing further important machine-elements the lecturer can refer to the machine-elements used as examples. In a next step the student is able to transform the knowledge of a higher degree of abstraction to the problems of this special machine-element. **Herztian stress** for example occurs between the roll barrel and the outer ring of a bearing. These two system components represent the isc roll barrel surface - bearing running part. The wsp of two interacting cog-wheels and their pairing of tooth profiles is another example for occuring Hertzian stress (Fig. 3). As a result in a higher level of abstraction the interpretation and design of tooth profiles and roll barrel surfaces is similar. The lecture does not have the ambition of treating all machine-elements completely. Its main aim is to impart the ability to understand and analyse unknown and complex machine systems. Wsp`s and supporting structures are tools which help to sort new elements into known basic knowledge. In this way the ability of independent synthesis is promoted. About 15% of the contents of the lectures treat non-mechanical mechatronic elements and systems. This helps to show the expansion of modern machine construction. One example system is the automatic driving train system again.

The lecture is done completely with the support of digital techniques of presentation. Therefore it is possible to include digital video sequences into the lecture and to impart knowledge whilst saving a lot of time.

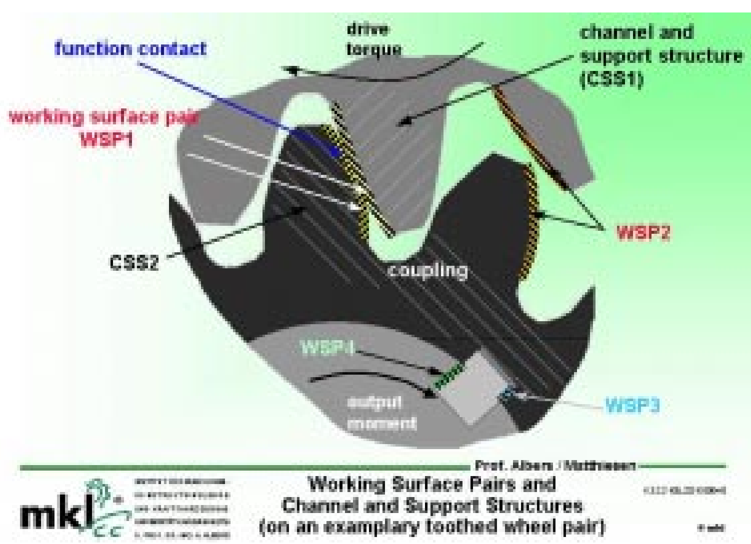

Fig.3: Working Surface Pairs and Channel and Support Structures

5.2 Exercise

According to the new teaching model the exercise is a special event. An exercise guiding assistant imparts special knowledge while acting and explaining in front of the students. This „guiding style“ is similar to the lecture, tutor-orientated and with little interactivity. Simplified, this guiding style can be called authoritarian and patriarchal. During the exercise questions and suggestions are welcomed, but the extent of the discussions is limited by the amount of students (275 students in the summer semester’99).

During the **exercise** the theory from the lecture is picked up and becomes more intense. Special exercise problems refer to the guiding elements and guiding systems which have been discussed in the lecture and in the workshops. The student learns to convert and transform the internalised knowledge to concrete problems.

5.3 Workshop

Main aim of the workshop is to impart the already mentioned soft skills. From the beginning consistent teamwork is expected and practised. Construction work is divided up by the team members independently, different experiences have to be communicated. In most cases students are not used to teamwork. Therefore this aspect has to be imparted under guidance of six assistants and eighteen student scientific aides during the weekly workshop. At the beginning of the workshop the attendants still intervene in the teamwork in an authoritarian manner. During the second and third semester the attendants withdraw more and more from the solution finding process. They only intervene to fulfil advisory or participatory tasks in the process. During these semesters this attendance is understood as a special form of coaching. This process leads to a continuously increasing independence of the students. During the first two semesters the students deal with an easy guiding system and the guiding elements. 18 compulsory and 9 optional workshops offer the possibility to take apart a mid-sized gearbox and to analyse the various system components. The workshop task during the first semester is the imparting of technical freehand drawing, the analysis of building parts in design and function, surface-analysis and measurement under consideration of various fabrication techniques and the analysis of fits and first synthesis considerations.

During the second and third semester machine systems with an increasing degree of complexity have to be designed. These events also take place in student teams. The teams have to define interfaces of the construction for themselves. Single constructions are coordinated, put together by the team and finally graded by the attendants. The final exercise is an industry-oriented construction-problem . Its solution is also unknown for the attendants [99/8].

6 IP

1. Lectures (4 hrs / semester week)
2. Workshop (3 hrs / semester week)
3. Project work (120 hrs total)

They are offered parallel in the winter semester as a main subject.

6.1 Lectures

The Students are introduced to product development of enterprises in lectures with particular reference to the requirements of small and medium sized companies. Based on practical experiences and examples from industry, the theory of systematic planning, design, cost control and management of the development and innovation process is introduced and discussed as a team-oriented adoption of effective techniques viewed a problem solving process. Strategies of development and innovation management, system analyses and team leading are presented and discussed. The lecture is designed for a limited number of participants (est. 20 students) and is a break from traditional lecturing arrangements. This offers the possibility of teaching in discursive form with the use of multimedia tools to aid presentation of the subject. If necessary the official time allotted to lecture can be relaxed to enable open-end discussions.

6.2 Workshops

In the workshops knowledge is actively built up and developed with the first real application experiences. This is achieved through:

- A direct and practical translation of the learnt methods directed to the development process.
- A simulation of group-dynamic processes by means of exercises. This requires a flexible timetable for the "Methods" and their application for each workshop.

A total of 13 Workshops covers the following topics:

- Team processes
- Hosting- and communication techniques
- Product profiling, list of requirements, project design
- Application oriented creativity techniques
- Online-research
- 3D – hand drafts
- TRIZ, ARIS, Invention Machine
- Introduction to patent law

Single workshops are accompanied by guests from industry as required (e.g. SAP, CAD-Manager, STN and other). A 3D-CAD education is given supplemental to the workshop in a 5-day crash-course.

These workshops are set up to deepen and extend knowledge and are not used for the direct concurrent support of the student project work.

6.3 Project work

The content in this project is the development of a product from the idea up to the virtual prototype (3D-CADModel) with an independent student development team. It is shown here as an example of an mid-sized enterprise at the Product-Development-Centre of the Institute with the attendance of the head of Inst. and his assistants as a simulated management and respective development teams.

Hardware and software equipment (MS-Project, Pro/Engineer, Invention Machine, IM-Phenomenon, Access to the Internet/WWW and Databases) is set up in closed working areas for each the project team. At the end of the project a presentation is given in front of the management. In certain cases the management awards prizes for the best solutions. Each team makes an evaluation of their group performance and their individual team members in a feed-back briefing. The results are handed to the management for a assessment.

6.4 Organisation

The number of participants is limited to 20 students. The selection of students is made in an assessment with the head of Institute and the responsible staff members participation in this selection process is a duty on all teaching staff.

This education module closes with an oral examination which is evaluated as a main subject within University course.

6.5 Experiences

A tremendous interest on this educational model is present within the students, in spite of the very high work-load required so that a candidate selection must always be made. A high motivation and keenness is shown by the students. The project work produced patentable product developments, the product presentations were to a professional standard including a number of functional prototypes. The most innovative and unconventional solutions have surprisingly translated into concrete product ideas (Fig. 4).

It shows that graduates of this subject, who carry out their Diploma work in industrial companies, are able to translate their knowledge directly and successfully as the relevant feedback shows. Also the initial evaluation discussions with Graduates of this module showed a tremendous acceptance by all kinds of industrial companies.

Therefore it can be stated that this Karlsruhe originated education model promotes a professional competence for graduates [99/5].

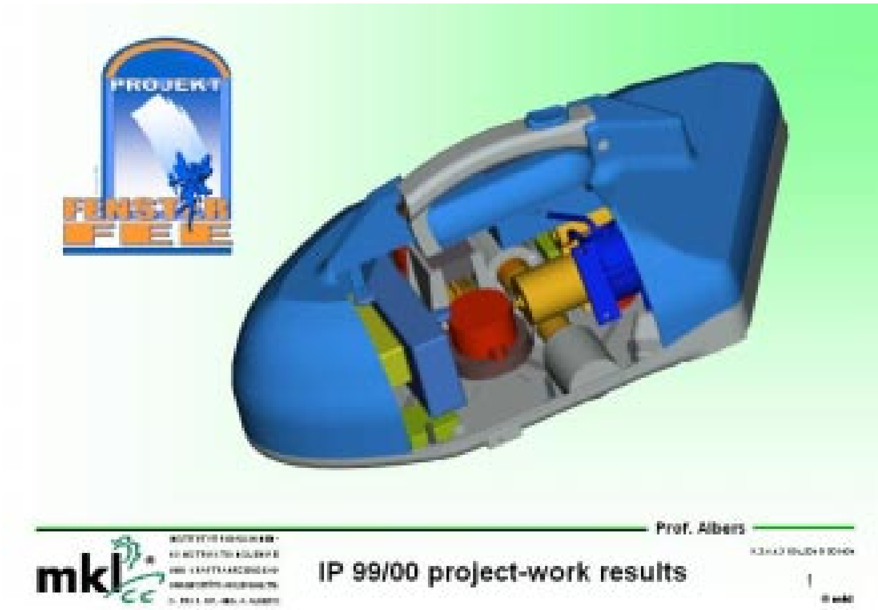

Fig. 4: Example of a result of project-work (Window Cleaner)

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