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CONCEPT DEVELOPMENT FOR INNOVATIVE PRODUCTS - A CHALLENGE FOR ENGINEERING DESIGN EDUCATION

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ABSTRACT

The complexity of new products steadily increases and therefore integrated engineering designers have to be skilled in various fields in order to develop innovative and successful products. This trend has to be considered in university education. Therefore, a new educational concept called "Concept Development for Innovative Products" (CIP) is proposed. In this subject the students are confronted with a vague task and are asked to develop and to present concepts for innovative products in teams of five. In this regard, CIP is a combination of three forms of teaching, which are presenting the working progress, discussing and lectures on demand. During mandatory working meetings the students have to present the project status to the supervisors and discuss the next steps with them. Furthermore, they can ask for lectures on specific engineering design methods which are presented using a comprehensive method catalog. The student feedback for CIP in the first semester was excellent and it is a very good enhancement for the curriculum. Consequently, the students are well prepared for a harmonic transition from university to their professional careers.

Keywords: design education, conceptual design, design methods, teamwork

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1 DEMANDS ON INTEGRATED PRODUCT DEVELOPERS

Developing innovative and successful new products is highly important for the business success and growth of technology companies (Bhuiyan 2011). However, in times of globalization and growing international competition, the frequency of new product launches increases (Anthony Di Benedetto 1999), which is just a sign of tightened product life and development cycles as well as shortened time-to-markets. Furthermore, the complexity of modern technology products steadily increases.

Therefore, today's technology companies are highly interested in multifaceted engineering designers with skills in various fields and able to work in an interdisciplinary and integrative engineering design context in order to cope with the highlighted challenges (Adamsson and Grimheden 2007). Young engineers employed in research and development departments are asked for subject-specific knowledge following a survey of the Association of German Engineers (VDI-Wissensforum 2008). However, it is becoming more and more important for them to be able to link their subject-specific knowledge and abilities such as skills in computer aided engineering tools with product development strategies and to gain a comprehensive view of all relevant decisions related to the development of new products such as, of course, technological as well as economic issues. This implies a consideration of all stages in product development from the planning stage to the detailed design stage by an integrated design engineer (Pahl et al. 2007, Riel et al. 2009). Beyond that, engineering, innovation and design has to be integrated in the field of engineering design (Jackson et al. 2009).

Furthermore, the demands on subject-specific and methodic as well as social and personal skills in the professional context increase (Jasper et al. 2009). In order to consider these trends in education and training, Riel et al. (2009) proposed a skill set of integrated design engineers based on the results of studies and collaborations with industrial partners. Different design and engineering skills such as innovation-driven design, sustainable design, responsible design, product lifecycle engineering and knowledge engineering are among these key skills which can be derived from the Design for X philosophy as illustrated in Figure 1 (Meerkamm et al. 2012).

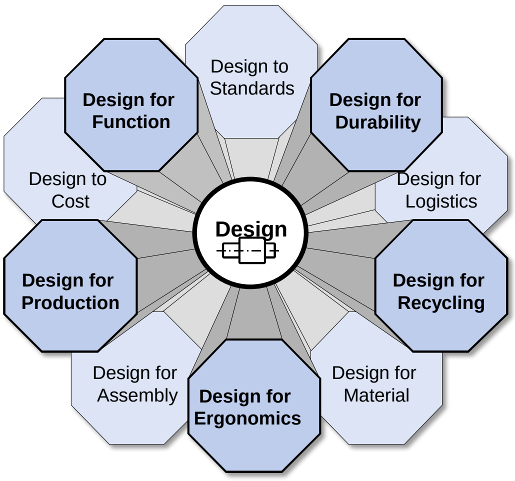

Figure 1. Design for X Aspects

In addition, social skills like networked collaboration and intercultural skills play a huge role in the engineering design context. These collaborative engineering skills are also to be trained by young engineers during their university education (Feldhusen et al. 2007). Since a designer's social skills, such as abilities for team collaboration and client communication, are very often crucial for the success of design projects (Lauche 2007), it is important to cultivate and to improve these skills as for example in student courses or seminars. Lauche (2007) therefore proposed a standardized format for observing and providing feedback with respect to social skills, for example in student projects and design education.

Overall, there is a wide understanding that modern engineering designers have to unite many talents and skills which also have to be considered in engineering education and training instead of focusing on mere technical and subject-specific skills in university education. Figure 2 shows a small selection of required skills for engineering design based on the skill set for integrated design engineers by Riel et al. (2009) and the framework for social skills in design by Lauche (2007).

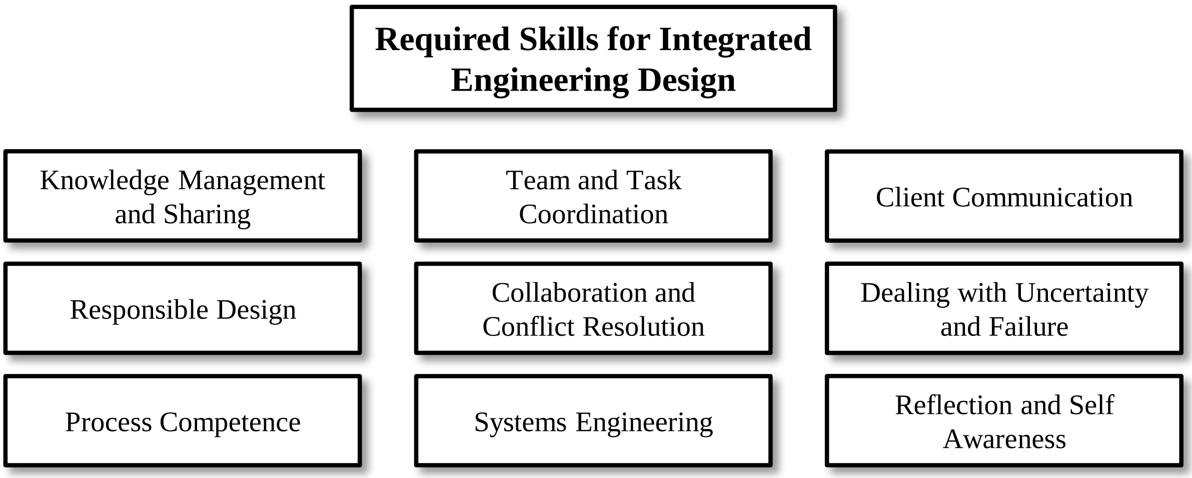

Figure 2. Required Skills for Integrated Engineering Design

However, in traditional engineering education much time is spent on teaching subject-specific methods and tools for later design stages such as the embodiment design and detail design stage following Pahl et al. (2007). For example, Meerkamm et al. (2009) describe concepts for the education of engineering designers, which are focusing on subject-specific basics and advanced subject-specific skills. Beside this, Feldhusen et al. (2007) propose a project, which aims at enhancing the students' collaborative skills in computer-aided engineering environments such as computer-aided design. In contrast to these courses, Hall and Childs (2009) discuss a non-linear progressive educational approach dealing with the co-education for diverse intakes focusing less on teaching and training subject- specific skills and abilities. Furthermore, Liebenberg and Mathews (2012) describe and discuss an engineering course, which covers innovative and entrepreneurial content of teaching. All these different educational approaches, however, only regard some of the illustrated required skills for integrated engineering design.

For that reason, a new student course called "Concept Development for Innovative Products" (CIP), which is particularly focusing on early product development phases such as the task clarification and the conceptual design stage was developed. Starting from a quite vague problem and job definition with industrial relevance, student groups of five are asked to develop innovative product concepts. In this regard, the students have to think first of all about their course of action and economic aspects such as the target group of their product before answering business questions like the planned sales volume and the planned market price. Thereafter, various methods of integrated product development are trained, such as idea generation and creativity methods like method 635 or brainstorming. Each group is asked to develop up to three innovative product concepts which also have to be reviewed as well as evaluated and are finally presented in front of all other teams and the educational staff during the examination.

2 CONCEPT DEVELOPMENT FOR INNOVATIVE PRODUCTS – THE NEW ELECTIVE SUBJECT

The aforementioned challenges on the education of tomorrow's engineering designers motivated the development of a new educational concept called "Concept Development for Innovative Products". This new elective subject aims at preparing the students for their future professional career. In the following, the prerequisites and objectives are highlighted and the organization of CIP is explained.

2.1 Prerequisites and Objectives of the Subject

The new elective subject CIP enhances the mechanical engineering curriculum since the summer term 2012. This subject can be selected solely by students of the following five master degree programs of the Faculty of Engineering: Mechanical Engineering, Industrial Engineering and Management, International Production Engineering and Management, Mechatronics, Medical Engineering. The second prerequisite is that students must have passed the course "Methodological and Computer Aided Design" successfully. Furthermore, the attendance of the lecture "Integrated Product Development" is strongly recommended since important content (e. g. basics in problem-solving, human behavior in product development, project management, controlling in development, trend research and scenario technology, complexity management) will be taught in this major subject. The advanced course CIP aims at training master students in various aspects of integrated engineering design which is why the accepted students have to provide basic knowledge of common product development methods.

The aim of this course is to work on a complex task in competition with other teams. The task requires the ability to use independently various methods learned from courses like "Technical Product Design", "Methodological and Computer Aided Design" and "Integrated Product Development" such as the development and design of technical products and systems from ideas to concepts (in particular in the early stages of the product development process).

In addition to that, an understanding of the complexity of such tasks from the later industrial working life is attained. On the one hand, great importance is attached to good self-organization and efficient project management and on the other hand the already learned abilities (e. g. DfX-oriented design, computer aided design, knowledge management, decision making) are also applied in practice. Therefore, this elective course is a perfect preparation for the subsequent careers of the students because future graduates are prepared in particular for working in research and development and a knowledge-intensive economy and society. Hence, CIP is specially tailored to meet the current demands of the job market and to prepare future product developers for difficult challenges. Thereby a harmonic transition from university to the working life is facilitated.

Another key objective is the combination of three different forms of teaching and learning approaches (Figure 3). The first one is presenting the working progress by the student teams, the second approach is the subsequent discussion between supervisors and students and the third one is presenting lectures on demand by the supervisors with the help of a method catalog. These three approaches are explained in greater detail in the subsequent subsections.

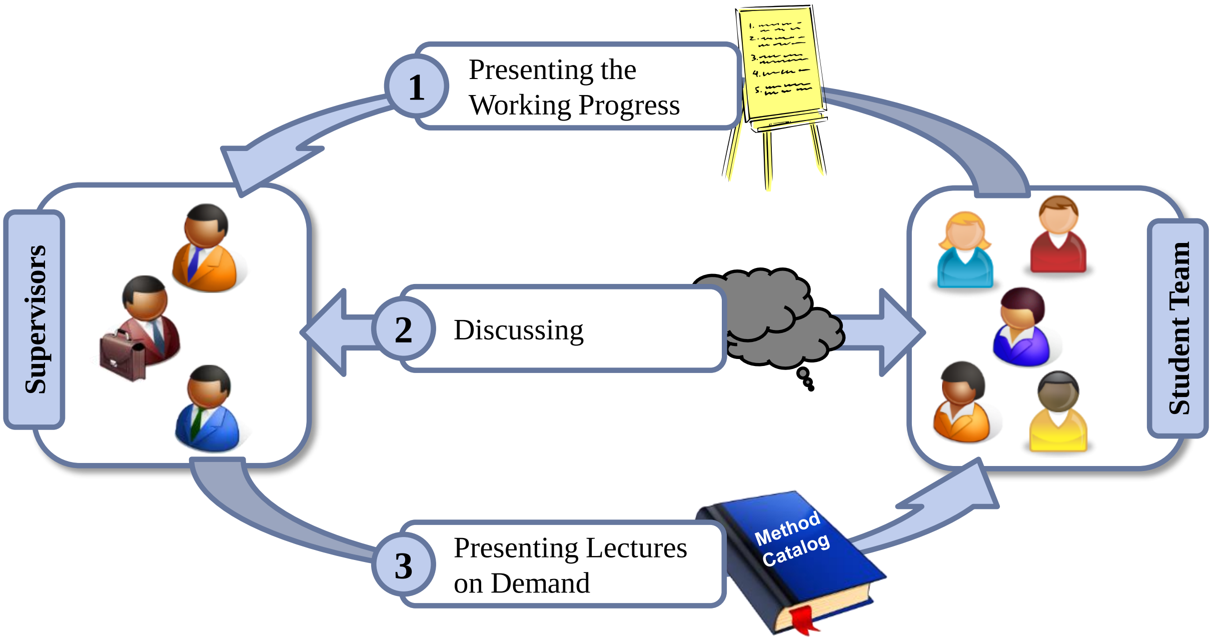

Figure 3. The three Teaching and Study Approaches

The three learning concepts of this elective subject focus on independent, mature work by the students. The participatory style of learning requires the exchange of information and experience among participants as it is an important milestone in the learning process. Thereby the steadily increasing relevance of self-regulated learning is taken into account (Stadelhofer and Marquard, 1998). A self-regulated learning process according to Puteh and Ibrahim (2012) consists of the following five elements: (1) an independent objective, (2) self-motivation, (3) selection of appropriate learning strategies and tactics (4) overcoming problems and (5) monitoring of learning progress. These factors are considered by the three learning approaches in the context of CIP.

From a social-cognitive point of view, self-regulated learning integrates the triadic interaction among the involved students (e.g. beliefs about success), their behavior (e.g. engaging in a task) as well as the

environment (e.g. feedback from a supervisor). The following three important characteristics of self-regulated learning are (Zimmermann, 1990, Zimmerman and Martinez-Pons, 2008, Zimmerman et al., 2011): self-observation (monitoring one's activities), self-judgment (self-evaluation of one's performance), and self-reactions (reactions to performance outcomes).
Thereby, students learn how to formulate and to ask questions in order to enlarge their own prior knowledge. As soon as learners participate in questioning, they are forced to be more active than in classical teacher centered lectures (Palincsar and Brown, 1984). According to Pokay and Blumenfeld (1990) and Pintrich and Schrauben (1992) and Pintrich (1989), the majority of the empirical findings on the relationship between self-regulated learning and the acquisition of knowledge or the students' performance indicate in general a significant correlation between the components of self-regulated learning and examination results.

2.2 Organization of CIP

The new elective subject is organized in the following three steps. After the presentation of the scope of tasks and some organizational matters during the kick-off meeting, the student teams are starting to work in obligatory meetings on their concepts for innovative products. The last step is a final examination during a presentation session.

The Kick-off Meeting

Since the maximum number of participants is limited to 15 students, it is necessary to select potential candidates according to certain criteria (e. g. current grades, number of semesters) after their registration. After this selection, three teams – each with five students – are formed by the supervisor. Thereby, an interdisciplinary team composition is desirable such as female and male students from different master degree programs. This team composition will be announced in the kick-off meeting.
Moreover, the organizational structure and procedure of the elective subject is presented in detail during the kickoff meeting. As part of the meeting, the task is explained as well as some helpful background information from the supervisors are elicited. After this meeting, the three teams will meet once a week for a fixed mandatory 90-minute working meeting.
For these working meetings, project houses are available for the student teams. These project houses are rooms especially designed for group work and offer an excellent working environment with laptops, presentation equipment, flipcharts and group tables. Therefore, during the whole course the student teams are enabled to act as professional and individual product developer teams provided with fully-equipped seminar rooms, state-of-the-art information technologies and constructions sets in order to apply and further improve engineering knowledge and skills (Figure 4). With these construction sets, the student teams can implement and communicate their ideas on the fly during their working meetings. Furthermore, they are free to make use of different sources of information and modern software tools which are also used in industrial practice. It is also self-evidently that the project houses can be booked by students at other times, too. This improves not only the time management but also the self-organization and communication skills of the students.

Figure 4. Two Student Teams in the Project Houses

The Working Meetings

The structure of the course builds up on weekly team meetings with obligatory attendance of all team members. The procedure of each working meeting is shown in Figure 3. The three key steps of each

meeting are first of all the presentation of the working progress, secondly the discussions between the supervisors and the members of the three student teams and finally the presentation of the so called lectures of demands by the supervisors.
During the working meetings, besides the professor two research assistants are present. Firstly, the three supervisors have to be informed briefly on the achieved working progress from each team and therefore the students have to provide information about the current state of their ideas and concepts. Therefore, the students have to reflect their work critically and think about their next steps. Moreover, the educational staff gets a good impression about the learning progress and as a result, an active monitoring of the students' work is possible.
Thereafter the educational staff asks critical questions and discusses with each student team not only how to proceed but also their ideas as well as specific technical and economical and socio-cultural issues. Such questions could be: What technical features make sense or are very important for the product to be developed? What sales volume is necessary for a certain turnover? Which customers or customer groups with which customer requirements should be targeted and how should they be impressed by the product?

Lectures on Demand
In addition to the presentation of the work progress by the students and the subsequent discussion, the lecture on demand principle is a particularly important part of the course. The students have self-evidently the opportunity to inform on useful methods independently but they have also the opportunity to ask for so called lectures on demand about specific topics. On request by the students, the supervisors give a short lecture on a particular method which may be applied by the students in their future work.
For this lecture on demand principle, a comprehensive method catalog has been developed especially for this course (see Figure 5). This method catalog includes all the essential methods (e. g. 6-3-5 Brainwriting, TRIZ-methods, Morphological Analysis, Quality Function Deployment, Failure Mode and Effects Analysis, Reverse Engineering, Kano Model, Target Costing) that are important in the early stages of product development. All methods have been didactically prepared with the help of more than 250 PowerPoint slides in total so that they can be explained to the students quickly. Thereby, the students can train and expand many of the required skills for integrated engineering design – as illustrated in Figure 1 – in this elective course.

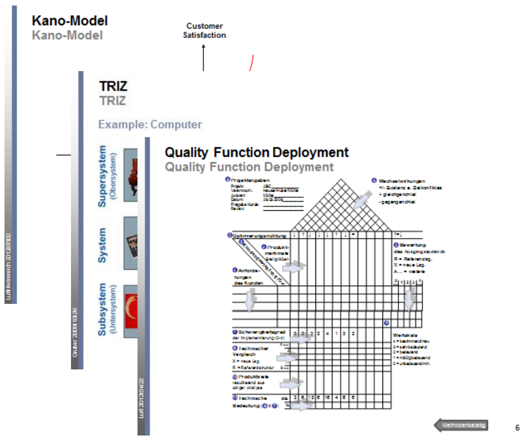

Figure 5. An Extent of the Method Catalog

The Final Examination
At the end of the semester, this elective course is completed with an examination. The final exam consists of two parts. The first part is a presentation followed by a short discussion and the second one is a detailed concept paper. The aim of the presentation is to convince the three supervisors of the developed concepts. For their presentation, each student team has 20 minutes. Further guidelines for the presentation (e.g. type, content) are not given. The presentation is followed by an approximately 15-minute discussion and therein not only the supervisors but also the two other student teams have the opportunity to ask critical questions.

Subsequent to the presentation, the student teams have to hand their detailed concept papers to the supervisors. The scope should not exceed ten pages. Exactly as for the presentation, no further guidelines regarding content or representation are given for the concept paper. The aim of the concept papers is the detailed explanation of the developed concepts with their specific product features and the resulting advantages and disadvantages as well as further background information.
The final grade of the elective course is the assessment of the presentation (50 percent) and the handout (50 percent). The main evaluation criteria regarding the presentation are the style and persuasive power of the presentation and the answering of the raised questions during the discussion. Furthermore, the level of innovation of the developed concepts, the adequate application of integrated design methods and the graphical layout are key aspects for the assessment of the handout.

3 JOB DEFINITION, ACTION OF COURSE AND STUDENT RESULTS

3.1 Job Definition

As mentioned earlier, the job definition for the elective lecture CIP is intended to be quite vague considering current trends and developments. In the last summer term, the case study of CIP was inspired by some current trends in mobility and demography. Following a study of the Berlin-Institute for demography and development (Kröhnert, Klingholz and van Olst 2004), many Germans leave outlying areas and move to urban agglomerations. In this regard, mostly environs are populated instead of inner cities. Therefore, many people are commuting to urban centers. Beside this trend for urbanization, society is shrinking and ageing since the portion of people older than 60 years old increases whereas the portion of people under the age of 20 decreases. Furthermore, the number of births decreases. However, an increasing need for mobility in older age groups can be observed. A fact that can be ascribed to better health in the old age. Therefore, even though society is shrinking, a growing traffic volume in metropolitan areas becomes apparent.
Moreover, modern technology companies operating in passenger transportation have to face a growing shortage of resources and are forced to develop business strategies in order to come up against increasing costs for commodities and resources which show in rising prices for gasoline, for example. Obviously, new concepts for urban mobility are required in order to accomplish these challenges which are subsumed in Figure 6.

Figure 6. Current Challenges for Urban Mobility Concepts

Therefore, in the past summer term, the student teams were asked to develop a concept for urban mobility, which aims at solving the highlighted problems and overcomes the illustrated conflicts. Moreover, the students were given some further requirements on their solution such as space for up to two passengers, the integration of social media technologies and the consideration of life style factors.
This job definition was given by a conceived company with international background. The student groups, thus, were intended to act as competing professional engineering teams and had to deliver their concepts as well as a presentation to the development board of the conceived company, which is represented by the educational staff.

3.2 Course of Action

Since CIP aims at training the students in the methodical development of new and innovative concepts, the focus of the lecture was set on the approach as well as the adoption of early engineering design methods. Hence, the students were supposed to specify the task as well as to develop an understanding of relevant strategic questions such as the planned market, the planned product launch date, the target costs and the planned sales volume during the first sessions. For this purpose, methods like the requirement list, brainstorming, mind-mapping could have been employed. Thereafter, the requirement specifications should have been determined based on the requirement list, the classification of these requirements into demands and wishes and a weighting of the demands. Methods and tools which are typically used for these purposes are Quality Function Deployment, KANO-model and Black Box. After the requirements are clarified, functions and their structure have to be determined. Thereafter, different operating principles for these functions and sub-functions have to be found and chosen. Methods which can be used in this context are, among others, the product and function structure as well as the morphological box. Finally, several concepts have to be devised and modularized based on some key aspects such as assembly, maintenance, and recycling. Moreover, the product concepts have to be divided in elements and components. In addition, technological risks, required development budget as well as the suitable marketing strategy have to be considered. Hence, the analogy method, project budgeting approaches and the marketing mix are suitable methods for these tasks.

3.3 Selected Student Results

The developed concepts for urban mobility show a wide spread of technical solutions as well as a high level of innovation. Among the results is the concept of a two-seated vehicle as shown in Figure 7, which can be maneuvered on the road as well as on the rail. This allows a wide operating area in sub-urban regions. Furthermore, the vehicle can be parked in automated parking garages. Features such as autonomous driving and remote controlled driving can avoid traffic jams and allow an efficient traffic control.

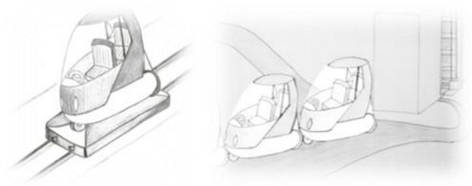

Figure 7. Two-seated Vehicle for Road and Rail

Another presented concept for tomorrows urban mobility is illustrated in Figure 8 and insipred by exisiting technical systems. The asymmetric design of the vehicle has many advantages such as a better stability and easy access for the driver in tight parking lots. Moreover, the vehicle can be loaded to trains for long distance journeys. Therefore, this concept is not limited to the design of a vehicle but also includes an idea for the infrastructure of tomorrow.

Figure 8. Asymmetric Vehicle and its Transportation for long Journeys

However, the presented results show that the development of concepts for innovative products requires not only subject specific engineering knowledge but also social and collaborative skills which have to be trained during university education. The applied learning of required methods and skills for integrated engineering design is thus a highly relevant educational issue. Therefore, the student teams were able to acquire subject-specific knowledge as well as to improve their social and methodical skills during CIP.

4 EVALUATION RESULTS, EXPERIENCES AND LESSONS LEARNED

As this new course has taken place for the first time in the summer semester of 2012, not only the evaluation results of participating students but also their overall impressions of the new elective subject are interesting. As a result it is possible to integrate preferences of students into the design and structure of teaching systematically as well as directly.

The students have the opportunity to submit anonymous evaluations of their courses. These evaluations are carried out at the end of every semester in order to improve the standards of teaching. The overall ranking result of the general questionnaire regarding CIP is very good. In all evaluation criteria

CIP received good or very good ratings and compared to all courses of the Faculty of Engineering it is almost always significantly better assessed by the students than the average rating.
In particular, the two criteria "the supervisors are addressing questions and concerns of students" and "relationships and interconnections to other study subjects are shown clearly" was evaluated as excellent by the students. The following comments of the students further substantiate the evaluation results: "It is great that methods learned in theory can be tried out in practice.", "Working together in interdisciplinary teams is fun.", "The presentation and communication training is very important for my future career.". Thus, not only the academic teaching staff but also the students have the opinion that one drawback of other lectures within master degree programs has been absence of subjects that cover team work. Therefore, it is important to learn about working in interdisciplinary teams, which should be done by working together in exactly such teams.
In addition to many positive responses from the students, two negative aspects were also addressed. According to the students, it would be desirable to predefine a specific procedure for the development of concepts or at least to prescribe a brief guideline for conceptual development. In contrast, the supervisors have the opinion that the attraction or objective of CIP is to find the procedure themselves. Nevertheless, a brief guideline will be developed for the following summer semester 2013.
The opinion of the students is that more lectures on demand with the help of the method catalog developed especially for this course should be presented and that the catalog has to be supplemented with more practical examples. The lecture-on-demand principle is also considered by the supervisors as an essential component of CIP and for this reason it will be intensified in the future but only if the other two components, "presenting the working progress" and "discussing" are not neglected.
To sum up, the evaluation results are providing a basis for a timely discussion between students and academic teaching staff in order to identify improvement possibilities.

5 CONCLUSION AND OUTLOOK

The professional requirements on integrated engineering designers steadily increase and comprise not only subject-specific skills but also creative talents and social skills such as networked collaboration and intercultural behavior. These demands on young engineers have therefore also to be considered in university education. The new elective subject "Concept Development for Innovative Products" takes account of these trends by asking for innovative concepts which have to be developed by student teams. These groups act as competing engineering design teams in a professional context and a self-regulated learning process. Thereby, the students are enabled to train their skills in a modern learning environment. In this regard, CIP enhances the engineering design curriculum reasonably by focusing not only on the knowledge of engineering design methods but also on their application. In the first run of CIP, the students were asked for a concept of tomorrow's urban mobility. Overall, their responses were very positive and the educational concept of CIP seems very promising. Nevertheless, the evaluation results will be taken into account in the revision of CIP. The method catalog will be revised and expanded until the upcoming semester.
In the future, however, it is also planned to involve companies from the nearer region. Consequently, the job definition, for example, is specified by selected companies in the upcoming semesters. Another possibility is that the team of supervisors is complemented by a company representative. As a result, not only the practical relevance of the tasks will be increasing but also the students can thereby network with employees from the participating companies. Due to the increasing global product development, student teams will be comprised of members from different nations in the future. As a consequence, students also get to know other methodologies taught in their colleagues' countries.

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