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TEACHING THEORY AND PRACTICE IN MECHATRONICS ENGINEERING

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1. Introduction

Engineers are a major propulsive motor for the economic development of companies and countries. Investments in a new technical and scientific generation are investments in a company's and country's competitive position. Meant are not only financial investments but also structural and organisational efforts. Discussions in politics, economy and academia are especially characterized by the introduction of new and innovative courses of studies. Hereunto mechatronics can be mentioned in particular.

The specific field of mechatronics means close interdependencies of mechanics, electronics, control engineering and software engineering in one functional unit. The aim is to improve the behaviour and capability of "classic" technical systems and to provide completely new functionality. Information about the system and its environment gathered by sensors is processed by software units and leads to an appropriate adaptation of the system by the containing actuators. Therefore mechatronic systems gain in importance and have been identified as pace making and key technologies for the future.

According to this the to-be engineers' and technicians' mechatronics education comes to the fore more and more. Industry is interested in a high-quality engineering education because a clear interconnection can be recognized between a company's economic power and the junior staff's promotion and development. Just to be able to survive in global competition it requires well educated employees.

The today's engineer needs consolidated technical and methodological knowledge as well as a multitude of "metadisciplinary" or soft skills. All-dominant in the specific field of mechatronics is the necessity and ability to approach the development process in a multidisciplinary and integrated manner. Engineers must be able to work in interdisciplinary teams, often in an intercultural composition and even at distributed locations. They must possess skills and knowledge not only limited to one discipline and must be able to work and communicate beyond a number of different specific fields as well as to develop technical systems in the sense of simultaneous and concurrent engineering. This means an integrated methodology and design not only of products but also of projects and processes.

This shift away from traditional working and organisational models to team work and crossfunctional and multidisciplinary projects actually requires an appropriate consideration and response in education. The main objective of mechatronics engineering education at the Institute of Engineering Design at the Ruhr-University Bochum is to qualify students according to these requirements and to enable them to cope with products and development processes as well as CA-x tools equally.

2. Objectives

The objective of this paper is to describe an education model developed and implemented at the Institute of Engineering Design which is fitted on the specific field of mechatronics and the product and processes complexity involved. Furthermore insights and experiences with the model employed are presented and illustrated by referring to representative case studies for mechatronic systems.

3. Engineering education

Since the early 1970s a shift has taken place away from thinking in boundaries of disciplines. The first step towards this has been the examination of "industrial plants" consisting of mechanical, electrical and electronic subsystems controlled by computers. Engineers required knowledge how to develop, produce and maintain these systems. Correspondingly a shift in education has taken place, too. Remarkable is a move away from only imparting domain specific content of teaching towards a combination of these knowledge fields.

3.1 Traditional engineering education

According to [Roddeck 2003] traditional engineering education has been strongly affected by theory dominated "activities" such as lectures, exercises and workshops. Bit by bit practical activities like hands-on training have been introduced. One reason for this is the fact that e.g. tools handling cannot be trained just by theoretical instructions. Nevertheless knowledge transfer by lecture still dominates the academic world just because a broad listenership up to some hundred people can be reached. In contrast to this very "economic" procedure in knowledge transfer the knowledge reception is not very efficient.

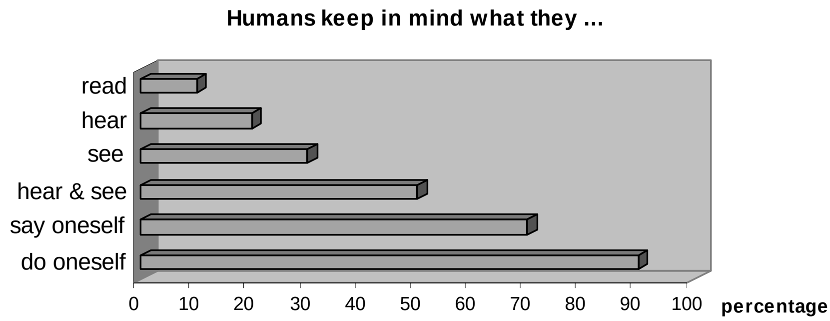

Figure 1. Efficiency of learning behaviour depending on the form of knowledge transfer

Figure 1 illustrates some major didactic insights presented in [Dudziak 1998]. Learning success strongly depends on the chosen form of knowledge transfer and reception. It can be recognized that information received through reading can be kept in mind by only 10% at average. Learning success improves furthermore by acoustic and visual presentations up to 50%. But a human's most effective learning behaviour can only be achieved by the so-called learning-by-doing. Educational courses with a claim to be as successful as possible must necessarily contain a multitude of these learning-by-doing elements.

Another important aspect that is asked for by industry but underrepresented in traditional engineering education is teaching of soft skills. These can be called "metadisciplinary" skills and elementary key qualifications in the today's business world. Traditional engineering education focuses on the transfer of technical and methodological know-how. The objective to teach soft skills up to a proportion of about 20% of the curriculum as demanded by industry has not really consequently been pursued by traditional engineering education.

3.2 Mechatronics engineering education

The specific field of mechatronics represents a rethinking and restructuring process of the world of employment. Employees from different disciplines work together and form a project team during the whole development process. They must be able to communicate with and understand each other and have to be open-minded for their colleagues' ideas and visions. Job training institutions and academic departments must establish a basis and educate engineers in such a way that they can work successfully in this changed business world. Mechatronics engineering education must counteract the described deficiencies of traditional education.

First of all it is not sufficient to impart knowledge solely in the fields of mechanics, electronics and software engineering. The focus of the courses must be to include and emphasise the integrative aspects, a fact that has been identified as a difficulty in understanding for students in [Jansen Flipsen 2004]. Of vital importance is the circumstance to establish an understanding of an integrated view on a system and its (industrial) employment. Still the to-be engineers must be educated in domain specific development methodologies, procedures, vocabulary and experiences. But furthermore they must "undergo" a process of cognition that the development of mechatronic systems stands for an integration of heterogeneous components and requires multidisciplinary communication and cooperation. Only thereby it will be possible to gain a shared concept of a future product and to come to an overall optimised solution.

During mechatronics engineering education it has to be shown that significant disadvantages can occur by using sequential development processes which in the majority of cases can lead to suboptimal mechatronic products. The objective is to teach a procedure in the sense of simultaneous and concurrent engineering [Brussel 1996]. Most important therefore are organisational abilities and steps which have the aim of multidisciplinary team work instead of the old-fashioned so-called "Throw-it-over-the-wall" way of thinking [Ehrlenspiel 1995].

Besides the possibility to develop different components at the same time the mechatronic development process can be especially characterised by another factor. Just the specific field of mechatronics makes it possible to test subsystems already in the early development phases by modelling and simulation. Approved methods therefore are e.g. virtual prototyping as well as soft- and hardware-in-the-loop. With the help of different CA-x tools problems and weak points can be recognized even without the existence of a complete prototype. Noticeable effects are shorter development times as well as time-to-market, higher quality and increased productivity.

Essential basis for the mechatronic development process and therefore one of the first aspects in education is the underlying methodology. The guideline VDI 2206 [VDI 2004] describes a flexible procedure model which is based on the V-shaped model on the macro-level and the cycle of problem solving on the micro-level as illustrated in figure 2.

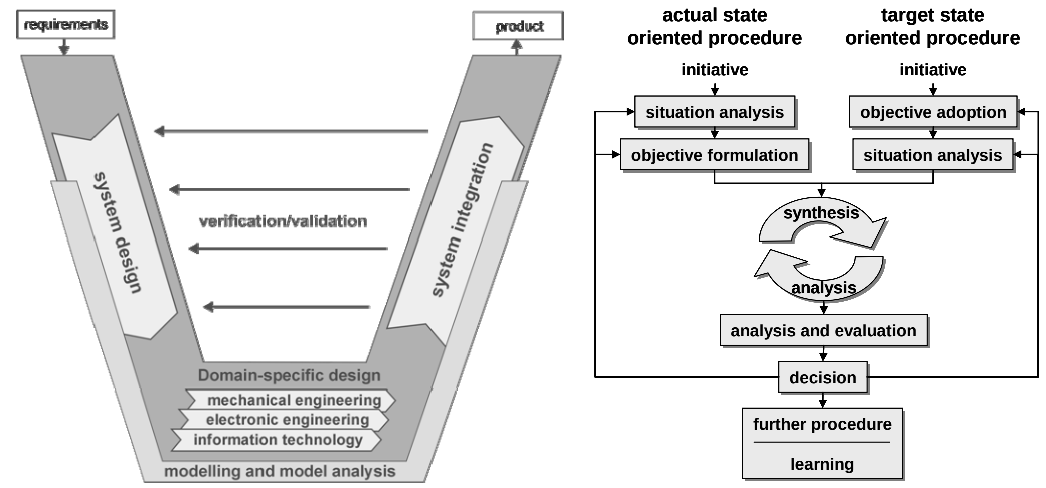

Figure 2. In VDI 2206 proposed methodology for mechatronic development

According to the V-model a first step is to determine and analyse the requirements of the future product. Afterwards an interdisciplinary conceptual solution is divided into subfunctions and domain

specific subsystems are developed simultaneously. These subsystems are integrated to one mechatronic product while being steadily verified and validated. The whole process is iterative as has been indicated at the right hand side of figure 2. Furthermore the process is throughout attended by modelling, simulating and model analysing activities. These physical and mathematical models in diverse CA-x environments play a major role in the mechatronic development process as has already been mentioned before.
According to the insights stated in the subchapter at hand the education's special requirements must be faced by a hereon fitted didactic conception.

4. Didactic conception and educational model

The fundamental idea of mechatronics engineering education at the Institute of Engineering Design is to enhance the students' professional (technical and methodological), social and personal skills and competences. The objective is to qualify young people to be able to succeed on the job market [Christmann Dworak Hellermann Putzmann Welp 2000]. Following learning content is at focus and will be illustrated and explained hereafter:

- Transfer of domain specific and integrative knowledge
- Learning and working in interdisciplinary teams
- Learning about and working with most important CA-x tools
- Planning and carrying out of projects in accordance to approved procedures
- Development, construction and dimensioning of mechatronic components and complete systems in accordance to approved methodologies
- Installation, implementation and testing of hard- and software
- Control, evaluation and documentation of work results

The basic components of mechatronics engineering education are illustrated in figure 3.

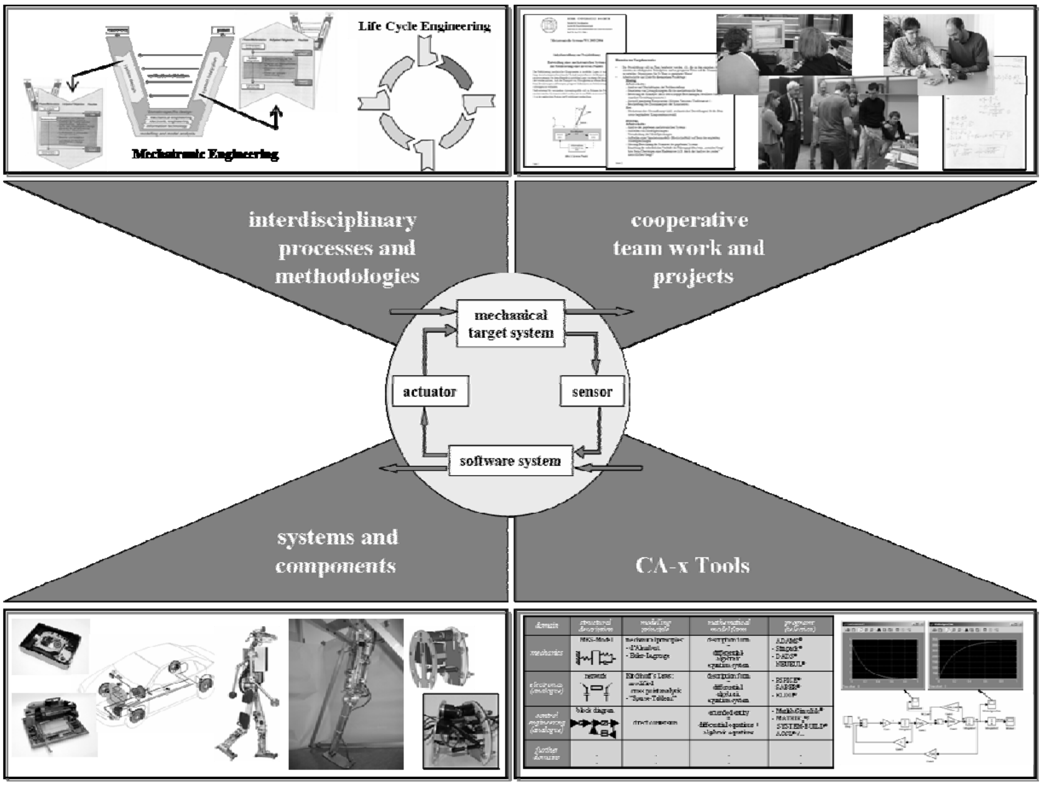

Figure 3. Elementary factors of mechatronics engineering education and some examples

The basis for mechatronics engineering education at the Institute of Engineering Design forms the lecture “Mechatronic systems” with duration of one semester. It is recommended to attend this lecture between the fifth and seventh semester. First of all elementary terms are introduced and the interrelationships between mechatronic subsystems are explained with the help of the reference model shown in the centre of figure 3 as well as illustrative case studies. A complete overview is achieved by discussing modelling and system design on a basis of system analysis.

The first guiding principle of the education model is to work and learn with systems and components as already shown in the bottom left corner of figure 3. It is dealt with machine and electronic elements as well as mechatronic components (sensors, actuators, signal processing and control systems) and their active principles. Furthermore their system integration is discussed under the focus of desired system behaviour. The lecture includes demonstrations with physical devices.

The second guiding principle is to educate the students how to work in accordance with approved methodologies and processes (upper left corner in figure 3). Students and engineers respectively need an ability to approach a problem systematically and to solve it methodically (right hand side of figure 2). Another focus is to explain the specific characteristics of mechatronic design and thereby to prepare students for with it associated team and project work. The theoretic content of teaching is applied in practice lessons. Already these ones are designed as discipline integrative projects. One essential component is to teach students how to use different development supporting CA-x tools as e.g. MATLAB and Simulink (bottom right corner in figure 3). The reproduction of mechatronic components and systems in virtual environment forms an outstanding factor to clarify the importance of a collective view on technical products.

The final third guiding principle is to educate and guide students how to learn and to work in cooperative unions. Dominant aspects are abilities to communicate and cooperate with project managers, domain professionals as well as team members on all levels of the development process. On the basis of their technical and methodological knowledge they are educated to independently plan, execute and evaluate their projects. This work is continuously facilitated and advanced by the “teachers” and department assistants. The first reason for this is the students’ need for support in manifold situations. The second one is to consequently improve the education’s quality. The students’ projects provide essential feedback for the faculty and this is implemented already during the projects as well as afterwards to be considered in the next terms. Thereby a continuous improvement process in engineering education is guaranteed.

The importance and advantages of educational projects in mechatronics engineering are e.g. listed in [Roddeck 2004] and [Albers Brudniok 2005] and are characterized by

- specification of an aim,
- restrictions in time, finance and persons,
- differentiation from other projects as well as by a
- project specific form of organisation.

Important factors for a project’s successful execution are especially the members’ social competencies. This circumstance is emphasised in [Nissl Ponn Lindemann 2005]. The essential skills which can be summarized under the topic social competencies are

- independence on the one hand and
- capability for teamwork on the other,
- creativity,
- decision-making and responsibility,
- competencies in communication as well as in conflict and time management,
- an efficient and goal-oriented working method as well as a
- distinct ability for presentation.

The objective of project-oriented education as best suitable in the specific field of mechatronics is to equip young engineering students with these key elementary qualifications and to promote their already existing soft skills. At the Institute of Engineering Design two different forms of projects are offered and carried out respectively. Two current design-and-build projects are described in the following two subchapters.

4.1 Semester finishing design-and-build project

First-time in winter semester 2003/2004 an integrative, mechatronic design-and-build project has been offered at the Institute of Engineering Design. It finally closes the semester and has a week-long duration. It is recommended to attend this project in connection with the lecture "Mechatronic Systems" after the fifth or seventh semester. The aim of the educational project is to produce a working, mechatronic system. Starting with a product idea the students act in accordance to the phases of mechatronic design. Depending on the number of course visiting students the design-and-build project is worked on in multiple teams up to five students. At the Institute of Engineering Design the project is regularly attended by up to 20 students. Hence all four or five teams work simultaneously and the teams and projects are facilitated by two institute assistants. Their major tasks are specialist advice, moderation and intervention of the independently operating project teams.

The whole project process is planned and also important intermediate results are worked out by the institute assistants beforehand. Specifications and recommendations for methods, auxiliary means and working results are worked out and provided to the students. Figure 4 illustrates the project in the winter semester 2004/2005 and basic development and working steps. The instruction has been to develop, design and produce a "Mechatronic Leg". The single development phases during the project work are continually documented by the team members. Additionally to the constant assistance temporarily limited meetings between students and assistants take place. They have the purpose of a perpetual exchange of ideas, information and results and are of special relevance for a successful time management.

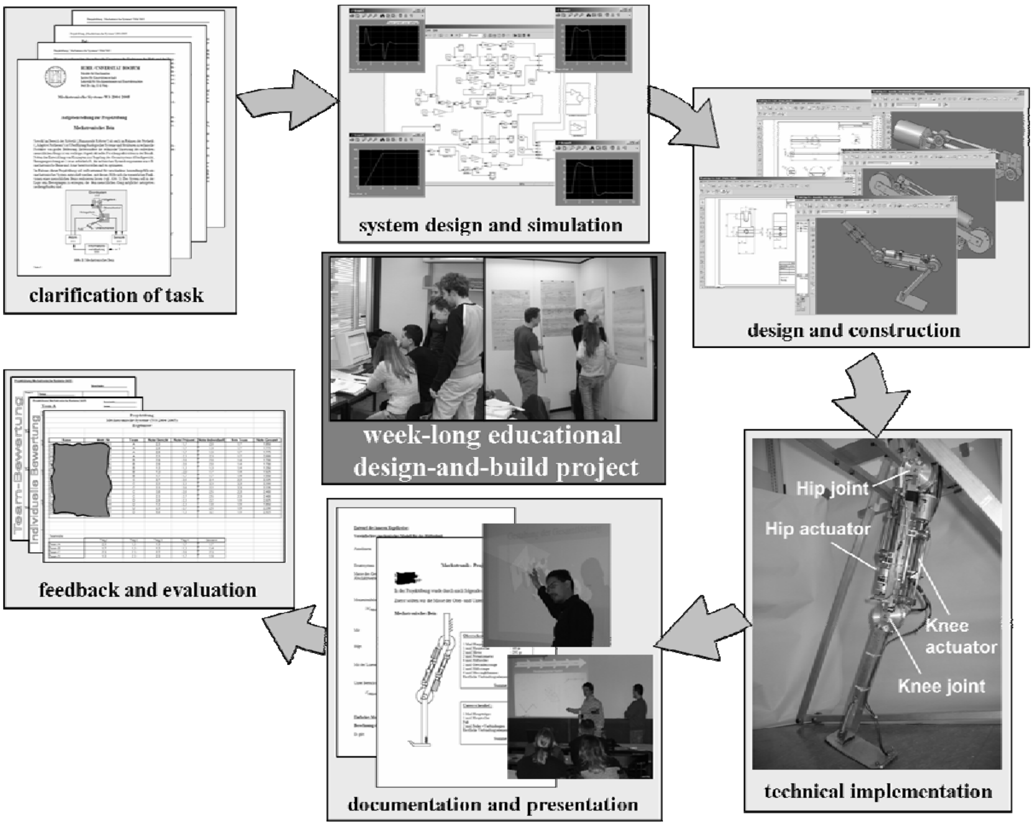

Figure 4. Week-long educational design-and-build project "Mechatronic Leg"

Especially for the students different potentials arise with the participation in a design-and-build project. First of all, a successful project realisation requires applying the students' technical competencies. Furthermore, methodological approaches introduced in lectures and exercises as well as computer-aided tools are tried out, experienced and scrutinised. On organisational level the students gain experience in coordination and self-organisation in time and working capacity as well as in the evaluation of revenue and expense. Finally, group dynamic processes are undergone on a social level. The students have to deal with different aspects as e.g. reactions to success and failures, cooperation and distribution of tasks, purposefulness and helplessness as well as differently existing and trained self-confidence and working and acting capacity.

4.2 Design-and-build project during the semester

Besides the afore described week-long educational projects shortly after semester also design-and-build projects during the semester take place. These have duration up to six months and are dealt with by a group of up to five students. The project's progression corresponds to the one of a week-long educational project as outlined in the foregoing subchapter. Figure 5 illustrates a current design-and-build project with the aim of development, design and production of a multifunctional locomotor system on the basis of "biomechatronic" components according to the biological model "snake".

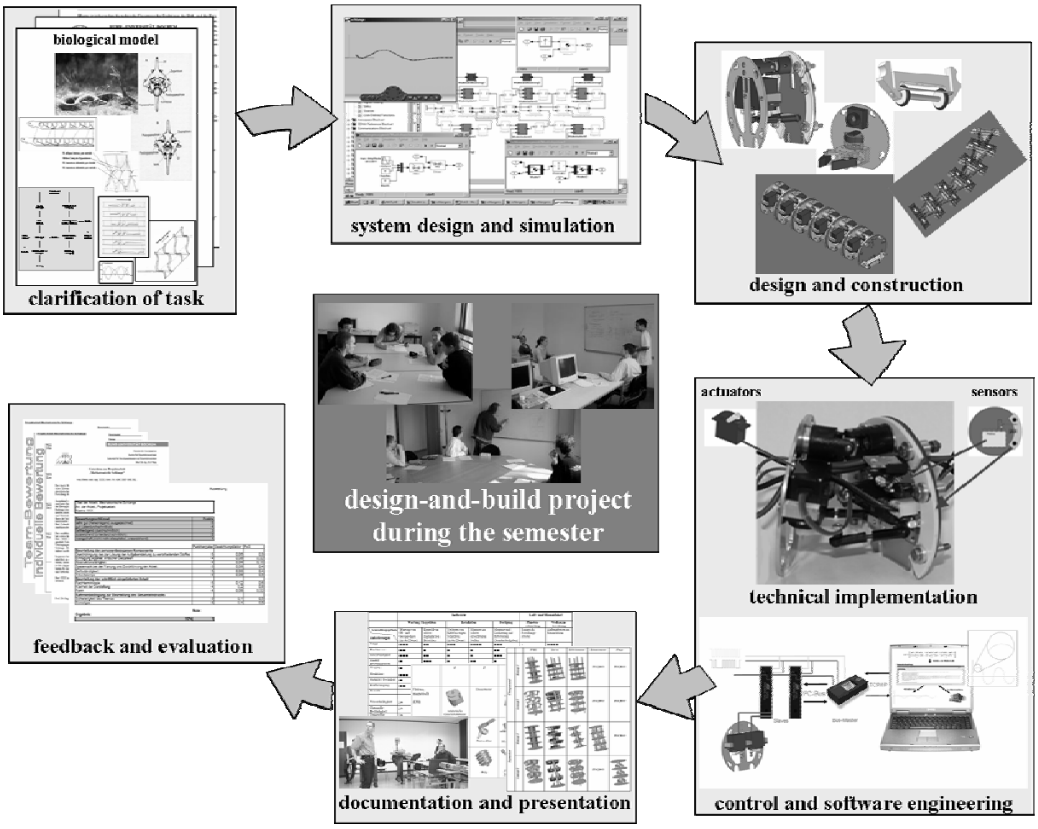

Figure 5. Design-and-build project "Multi-functional locomotor system *Snake*"

Major project objectives have been analysing activities of biological solution principles and synthesis of snake-like locomotion mechanisms as well as conception, design and implementation of actuators, sensors, hard- and software and the production of a working, modular prototype. The project actually is at final stage and has already been evaluated as very successful.

Both week-long projects and those during the semester make it possible for abstract lecture contents to become intuitively understandable. Intensive dialogues within team members support new insights. Students realise in how far a lack of knowledge can be compensated by an exchange of experience, how to organize their own work and the work of the whole team as well as how to observe the rules and keep a term to reach the team's aim. Finally they learn how to document their working steps and results as well as to present them to their "colleagues" and the "project managers".

5. Conclusion

Lectures and exercises in mechatronics engineering education have the aim to impart a basic understanding of systems, components and processes in mechatronics engineering and design. They provide the fundamentals consisting of technical and methodological knowledge. The importance of social competencies especially in the specific field of mechatronics has been presented in the text at hand. Two different forms of design-and-build educational projects are described in the two fore-going subchapters. These are steadily evaluated by the institute's staff to secure and improve the quality of content of teaching and curriculum, on the one hand. Basically with the help of interviews of students and institute assistants as well as direct observation of the projects essential insights are gained and fed forward to future educational courses. On the other hand the projects have the major objective to improve young engineering students' and to-be engineers' job capacity.

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