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TEACHING "COUPLING COMPETENCE" BY MEANS OF INTERDISCIPLINARY PROJECTS

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1. Introduction

This paper describes two interdisciplinary student projects aimed at the improvement of a decisive key competency called "coupling competence" (*in German: Ankopplungskompetenz*). In these projects senior students and master students of mechanical engineering, mechatronics, and applied physics were collaborating in order to develop mobile robots for different purposes. The students were jointly advised by professors of design in mechanical engineering, economics, applied computer science, and technology management. In this paper the notion "coupling competence" is elucidated, the importance of project based learning (PBL) for the mediation of design capabilities as well as key competencies is highlighted, the projects, their outcome, and observations in the projects are described, interpretations are attempted, and conclusions about success factors and problems are drawn.

2. "Coupling competence"

Recent studies concerning the competence of graduates of engineering schools indicate a prominent need for enhancing key competencies of the students [Rychen et al. 2005]. In this context a competency is more than just knowledge and skills. It involves the ability to meet complex demands, by drawing on and mobilising psychosocial resources (including skills and attitudes). For example, the ability to communicate effectively is a competency that may draw on an individual's knowledge of language, practical IT skills and attitudes towards those with whom he or she is communicating. Graduates from engineering schools need a wide range of competencies in order to face the complex challenges of today's product development. This wide range of competencies can be grouped into four categories called key competencies:

- **ability to use tools interactively**: graduates from engineering schools need to be able to use a wide range of tools for interacting effectively with the environment: both physical ones such as information technology and socio-cultural ones such as the use of language. Graduates need to understand such tools well enough to adapt them for their own purposes – they should be able to use these tools interactively.
- **ability to interact in heterogeneous groups:** in an increasingly complex and interdependent product development environment graduates from engineering schools need to be able to engage with others and since they will encounter people from a range of backgrounds, it is important that they are able to interact in groups which are heterogeneous in terms of age, gender, ethnic background, technical discipline, skills and hierarchical level.
- **ability to act autonomously:** graduates from engineering schools need to be able to take responsibility for managing their share of the product development process and act autonomously even in complex and difficult situations.

- **"coupling competence"**: graduates from engineering schools need to be able to understand any engineering discipline besides their own field of specialisation to an extent that allows them to formulate requirements, to understand general functionalities, to define, discuss, and negotiate interfaces, and to analyse and evaluate solutions. Graduates need to able to perform plausibility checks with any information in the broad field of engineering so that they can take part in the steering of complex product development processes.

These categories, each with a specific focus, are interrelated, and collectively form a basis for the further development of engineering curricula. The importance of the "coupling competence" as a recent addition is supported by the ever growing knowledge in engineering which requires a even stronger specialisation of engineers in product development. Only by means of this competence the ever increasing number of specialist in more complicated areas will be able to communicate efficiently and effectively in the future.

3. Project Based Learning

The same stakeholders who require an enhanced education in terms of key competencies (e.g. the accreditation organisations, the governments and their agencies) also require a broad and deep foundation of graduates of engineering schools in terms of scientific knowledge and skills. It is therefore nearly impossible to dedicate the limited time spent in lectures and tutorials to other education forms which are more appropriate to enhance key competencies. As a consequence, the most promising possibility is to integrate the endeavours aimed at supporting the development of key competencies into parts of the curricula that were already a bit different - the projects intended to learn engineering design.

Many acknowledged educators and researchers agree that teaching engineering design is the most challenging and simultaneously the least straight forward part of engineering curricula [Dym et al. 2005]. Evans et al. [1990] even state: [engineering design] "seems to occupy the top drawer of a Pandora's box of controversial curriculum matters, a box often opened as accreditation time approaches". Many publications highlight the insight that the most promising form to teach engineering students the ability to design (not theoretical knowledge about design) are realistic, open ended problems to be solved in teams, i.e. project based learning [e.g. Dym et al. 2005, Stetter & Ponn 2005, Hoffman et al. 2005, Thigpen et al. 2004, Stone & Hubing 2002, Hanesian&Perna 2001, Felder & Silverman 1998]. The main characteristic of design projects is that they provide experiences in accordance to Kolb's model of experiential learning [Kolb 1984]. In the educational area interdisciplinary projects with mobile robots have found considerable successes [e.g. Anderson & Jones 2005, Steidley et al. 2004, Dillard 2004].

In the described projects the focus was not only on the design outcome but also on the design process. The students were urged to plan, control, and document their development process and, in the second project, also to calculate product development and production costs of their product. For both products a combination of mechanical parts, electronic hardware, and software was necessary to fulfil the task. Therefore the "coupling competence" of all team members could be observed and maybe enhanced (see conclusions).

4. Design Projects

The presented insights are based on experience resulting from two product development projects with senior and master students of mechanical engineering, mechatronics, and applied physics. In the first project a prototype of a mobile robot that was intended to demonstrate an innovative dynamic drive system was developed. In the second project a mobile robot platform for the detection of blocked persons e.g. in collapsed houses was developed. In both projects the mechanical parts, the electronic hardware, and the software of the products had to be developed and the robots had to be built in the concept design workshop, in the mobile robots laboratory and in the mechanical workshop of the University.

4.1 Prototype of a Dynamic Drive System

In the first project a prototype of a robot for demonstrating an innovative drive system was to be developed and built. The innovative drive system that is already registered as a patent is based on the concept to use the torque of drive motors (more exactly the torque differences between wheels) to steer four independent axes of a robot. The design of the developed prototype is shown in **Figure 1**, the final presentation of the (simplified) physical prototype is shown in **Figure 2**.

Figure 1. Dynamic Drive System Robot - Design

Figure 2. Presentation of the Prototype of the Dynamic Drive System

The distinct characteristic of the innovative drive system is the absence of dedicated steering motors. By means of angle encoders applied at the four steering axes and highly dynamic control algorithms it is possible to steer the robot only by means of the four drive motors. This characteristic allows simpler and simultaneously more robust mobile robot concepts. It is also a main advantage of this concept that the resulting robot is able to drive directly in any direction without time and space consuming turning manoeuvres. Furthermore, a robot based on the dynamic drive system is able to turn around its own centre. This characteristic is very important if cameras or equipments are mounted on the robot which can only be used in a certain orientation. The innovative dynamic drive system shares this advantages with omni drive systems [compare e.g. Ashmore & Barnes 2002], but has reduced friction as well as easier controllability and offers the possibility to determine an exact position and orientation from an analysis of the angles of the steering axes and the angles of the drive wheels. Another intended characteristic of the developed prototype is the exclusive used of standard, state of the art components and interfaces, such as CAN Open. It is important to note that the design in **Figure 1** is much more elaborate than the prototype in **Figure 2**. This is caused by the fact that the mechanical design required too much time and that the students in charge of electronics and software needed a platform very early to be able to test and develop their share of the project. This problem of synchrony in interdisciplinary student projects is also discussed in the next section.

4.2 "Rescue Me" Robot Platform

In recent years mobile robots for rescue operations have found increasing attention (e.g. Wang et al. 2004, Hirose & Fukushima 2002). As an assistance in efforts to detect, to communicate with, to supply, and to save victims trapped for instance in the rubble of a collapsed building, mobile robots about the size of large toy truck could enter the ruins before the site is secured. The requirements such robots face are numerous and diverse. During the project, members of the team frequently were in contact with the "Technisches Hilfswerk", a large German state organisation engaged amongst others in the detection and rescue of victims of different catastrophes. This contact helped to develop a mobile robot platform, shown in **Figure 3**, which is suited to meet the most important expectations of rescue organisations. In upcoming projects further parts of the mobile robot are to be developed, for instance a flexible arm holding a (infrared) camera, a microphone, and a loudspeaker.

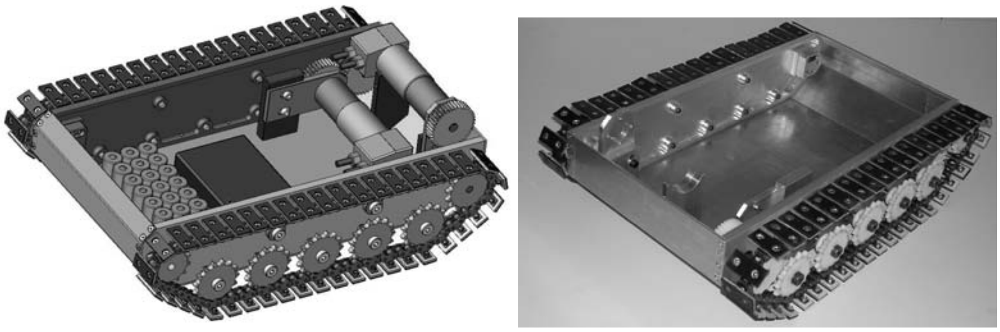

Figure 3. "Rescue Me" Robot Platform – Design and Realization

5. Observations and Interpretation

In this section observations made during advising the student projects are reported. Subsequently these observations are interpreted and success factors for and problems in interdisciplinary student projects aimed at enhancing design capabilities and key competencies, simultaneously, are listed. This section is divided into five main categories:

- **core design activities (product activities):** activities in the different domains which change the models of the product to be developed (e.g. sketching, drawing, calculating, CAD modelling) and activities that change the product itself (e.g. production of parts, assembling, programming),
- **planning and controlling the design process (process activities):** activities which aim to structure, prearrange, and monitor the shared process,

- **decision making:** activities which aim at selecting both possible product and process variants
- **communication and negotiation:** activities which aim to transfer information, to achieve a common understanding, and to allow common decisions, and
- **individual characteristics and characteristics of the teams:** characteristics of individual members of the project team which foster or hinder success, and characteristics of the whole project teams.

5.1 Core Design Activities

In the presented projects the product activities were assigned to individual team members in their specific domain. This kind of procedure was supported by the advisers as it represents the procedures in industrial companies. A teaching scenario were each student has to work in another than his/her expertise field was consciously no chosen as it would be less realistic and endanger the project success. However, such scenarios in general may also be appropriate to enhance the "coupling competence. As a consequence of the chosen scenario, the work in the product activities were not intended to enhance the "coupling competence" directly and are therefore not analysed in detail. Still, the observations of the advisors indicate a positive and effective learning experience for the students in reference to their design capabilities.

5.2 Planning and Controlling the Design Process

The rough planning of the product development process did not present a large problem for the teams. A coarse life-cycle oriented process model (planning / task clarification – concept design – detail design – production / assembly) was successfully used in both projects throughout the disciplines. In the second project the design team was asked to use the V-model [compare e.g. Bernardi et al. 2004] of mechatronics as a basis for their project planning. However, the team did not feel that they needed a fine planning of their project. The team members saw no contradictions to the V-model but also no added value by explicitly using the model.

In the V-model the domain specific parts of a product are developed in parallel process sections. In general, such procedure was desired in the project as each team members should carry a possibility for his/her share of the product to be developed. However, different domains cannot always work in parallel process steps because the length of certain activities was found to differ greatly over the disciplines. For instance, the development of electronic hardware mainly consisted of a selection and procurement of predefined modules. On the contrary, many mechanical parts had to be developed and produced specifically for the respective product. Especially in the first project this fact proved to be a large problem for the project team, as the intended mechanical hardware was not existing when the others team members needed it for the time consuming optimisation and launch phase for the electronic parts and the software.

It seems that the merit of one-term projects for the teaching and training of project planning and process models is somewhat limited as such projects are usually simple enough that a successful project outcome can also be realised without using elaborate process models. The authors conclude that other teaching scenarios such as business games are more useful for teaching and training the use of project planning techniques and elaborate process models.

In the author's experience the problems in synchronizing activities in different domains can also be observed in industrial product development processes. The experience with this problems and the approaches to overcome these problems therefore reflect reality and can lead to an improved understanding of an interdisciplinary process and can thus enhance the "coupling competence".

5.3 Decision Making

Intentionally the advisors played the role of customers which stated requirements to the students but left the decision making largely to the project teams. In both projects it could be observed that a successful collective decision making was possible after a short initial phase within which a shared understanding was achieved. Obviously, acquiring the understanding of the functionality in the other domains was possible and an effective and efficient negotiation of interfaces and the overall functionality and design was possible.

It can be hypothesized that “coupling competence” in situations were decisions are to be made is extremely important for the project success, as product development is to a large degree determined by the decisions [Hazelrigg1999]. In the observed project the ability to arrive at joint decision was very high, which might be caused by an enhanced “coupling competence” but also by the characteristics and previous knowledge of the students (compare section 5.5).

5.4 Communication and Negotiation

Even in the domain of engineering design it is reported that different languages are employed to represent engineering and design knowledge at different times, and the same knowledge is often cast into different forms or languages to serve different purposes [Dym et al. 2005]. In a mechatronics project for instance written or spoken text, formulae, function structures, sketches, engineering drawings, CAD models, block diagrams, class diagrams, and use case diagrams are used to represent characteristics of the product or the process. These languages are often domain specific and are often difficult to understand for persons from other domains. However, in the observed projects this fact did not represent as much of a problem as expected. This was probably caused by two facts: On the one hand, some contents did not have to be discussed in detail and therefore domain specific product models did not have to be understood by every team member. On the other hand, in the team meetings important domain specific model of the product were presented and explained by the respective team members. These explanations fostered a mutual understanding of the product [compare Minnemann 1991]but also enhanced the understanding of the experts themselves by repetition and reflection. Probably especially explaining (which also means to reflect upon the knowledge of the partner in the conversation) and negotiating in projects enhance “coupling competence”.

5.5 Individual Characteristics and Characteristics of the Teams

In both projects the students did not only contribute the domain specific knowledge they acquired during their studies but also knowledge, experiences, and skills from their private life, such as hobbies. One of the students was chief of a fire brigade, others were assembling engine powered model cars (which in a sense are also mechatronics products) or bikes. This background of the students was found to be very important. The knowledge and skills may have been randomly dispersed and rather unstructured but nonetheless eased the interdisciplinary discussion. Also the fact that some of the team members had a prior education as mechanics and worked part-time greatly influenced the product and process success.

As stated earlier, in interdisciplinary projects students suddenly become experts in their domain and have to teach and advise other team members. This change of position in the education system (this change could be characterised as a change from apprentice to expert/teacher) might be one of the cornerstones of success of interdisciplinary project based learning. The team members have to reflect their own knowledge and the knowledge of the other team members.

The reflection of the individual and team characteristics consolidated the impression that the “coupling competence” was somewhat enhanced by the interdisciplinary but also made clear that the individual life and knowledge of team members always plays a prominent role with regard to the development of key competencies.

6. Conclusions

The main objective of the presented project was to analyse teaching possibilities for “coupling competence”. The notion “coupling competence” summarizes the ability of graduates from engineering schools to understand any engineering discipline besides their own field of specialisation to an extent that allows them to formulate requirements, to understand general functionalities, to define, discuss, and negotiate interfaces, and to analyse and evaluate solutions.

This paper cannot (and is not intended to) prove that engineering education can really achieve an improvement of key competencies such as “coupling competence”. However, the comparison with experience described in literature and the experience in the described projects clearly indicates that an interdisciplinary project based learning environment is the most promising approach to observe, reflect, and enhance the “coupling competence”. Such projects are a challenge for the advisers as they also have to act outside their accustomed field of expertise. The experience at the University Ravensburg-Weingarten shows that such projects, besides the reported problems, are a valuable addition to the more conventional teaching and learning scenarios. Further teaching and learning scenarios that may foster coupling competence are “student-centred learning” (e.g. McGill and Beaty, 1992), “ or “storytelling” (e.g. Lindesmith 1994). The potential of these techniques is intended to be explored in further research.

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References

Albrecht, S., Brauchle, C., Frick, A.., Gonzales, V., Pelzl, M., Wolf, K. “Projektbericht Rescue Me – Entwicklung und Aufbau eines mobilen Roboters”. 2005 (not published)

Anderson, K., Jones, C., “Autonomous Robotic Vehicle Design”, Proceedings of the Southwest Regional ASEE Conference, ASEE 2005.

Ashmore, M., Barnes, N., “Omni-drive robot motion on curved paths: The fastest path between two points is not a straight-line", Proceengis of the Australian Joint Conference on Artificial Intelligence, Dec., 2002, pp. 225-236.

Bernardi, M., Bley, H., Schmitt, B., ”Integrating a Mechatronics-oriented Development Process into a Development Departmen”, Proceedings of the 37th CIRP International Seminar on Manufacturing Systems, pp. 265-270, Budapest, 2004

Dillard, W., “Revisting the Autonomous Robot. Finding the Engineer within the Student”, Proceedings of the 2004 AEE Conference, Salt Lake City, 2004.

Dym, C. L., Agogino, A. M., Eris, O., Frey, D., Leifer, L. J., “Engineering Design Thinking, Teaching, and Learning”, Journal of Engineering Education 1, 2005, pp. 103-120.

Felder, R., Silberman, L.,”Learning Styles and Teaching Styles in Engineering Education”, Engineering Education, 78 (7), pp. 674-681, 2002.

Hanesian, D., Perna, A. J. “An Interdisciplinary Collaborative Approach in Teaching Freshman Engineering Design”. Proceedings of the International Conference on Engineering Education, Oslo 20001.

Hirose S., Fukushima E.F., “Development of mobile robots for rescue operations”, Advanced Robotics, Volume 16, Number 6, 1 September 2002, pp. 509-512(4).

Hazelrigg, G.A, “An Axiomatic Framework for Engineering Design,” Journal of Mechanical Design, Vol. 121, 1999, pp. 342–347.

Hoffman, A H., Liadis, K. N., Boettcher B. “Work in Progress - Developing a Project Based First Year Design Course” Proceedings of the 35th ASEE/IEEE Frontiers in Education Conference, Indianapolis 2005.

Kirys, A., Labacheuski, I., Malinouski, A., “Project Report: Highly Dynamic Robot Chassis”. 2005 (not published)

Kolb, D. A., “Experiential Learning. Experience as the Source of Learning and Development”. Prentice-Hall: 1984.

Lindesmith, K., “The power of storytelling”, Journal of Continuing Education, Vol. 25, No. 4 (1994).

McGill, I. and L. Beaty, “Action Learning in Higher Education”. In: “Action Learning” , Kogan Page Limited: London.1992, p. 236 - 253.

Minneman, S., “The Social Construction of a Technical Reality”, Doctoral Dissertation, Stanford, California: Stanford University, 1991.

Rychen D.S., Salganik L.H., and McLaughlin M.E. (eds.)”The Definition and Selection of Key Competencies - Executive Summary”. OECD: 2005.

Steidley, R, Bachnak, W., Lochachit, W., Sadovski, C., Ross, C., and Jeffress G., “A Remote Controlled Vehicle for Interdisciplinary Research and Education”, Proceedings of the 2004 AEE Conference, Salt Lake City, 2004.

Stetter, R.; Ponn, J.: Workshop “Lehre gestalten mit Hilfe der Erfahrung aus dem Berufsleben“, In CiDad News (2005) 2.

Stone R. B. and Hubing N., “Strikimng a Balance: Bringing Engineering Disciplines Together for a Senior Design Sequence”, Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition. ASEE: 2002.

Thigpen, L., Glakpe, E., Gomes, G., McCloud, T., "A Model for Teaching Multidisciplinary Capstone Design in Mechanical Engineering" Procceding of the 34th ASEE/IEEE Frontiers in Education Conference, Savannah, GA, 2004.
Wang, J. , Lewis, M., Hughes, S. "Gravity-Referenced Attitude Display for Teleoperation of Mobile Robots"Proceedings Of The Human Factors And Ergonomics Society 48th Annual Meeting 2004.

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