COOPERATION-FOCUSED EDUCATION IN MECHATRONIC ENGINEERING DESIGN PROJECTS

Sebastian SCHMIDT[1], Quentin LOHMEYER[2], Stefan KREBS[1], Sören HOHMANN[1] and Sven MATTHIESEN[1]
[1]Karlsruhe Institute of Technology (KIT), Germany
[2]Swiss Federal Institute of Technology ETH Zurich, Switzerland

ABSTRACT
Mechatronic engineers are essential joints within modern product development processes. They closely interact with the classical domains of mechanical, electrical and software engineering in order to support the design of customer oriented products of high integral functionality. Due to this, their day-to-day business in practice is strongly characterized by intensive personal cooperation including a high amount of discussion, negotiation and decision-making regarding present design issues.
In education of mechatronic product development primarily the challenge of consistently imparting well-selected knowledge of mechanical, electrical and software engineering is discussed. Resent publications focusing especially the consideration of functional and structural interdependencies between these domains in the context of measurement and control technique. Nevertheless, in addition to train the solving of technical problems, students of mechatronic engineering must develop cooperation competencies to even cope with strategically and organizational issues at an early stage of their studies.

Keywords: Cooperation, mechatronics, project-based learning, team decision making

1 INTRODUCTION

This paper presents an educational concept of project-based learning focusing the cooperation in mechatronic engineering. The concept is currently tested in single pilot studies and it is meant to be fully implemented in the winter term of 2014 with about 100 undergrad students. In the first step of the planed project the students are subdivided into 20 groups with 5 persons each. The teams' project task considers the development of small vehicles, which should be able to automatically identify and collect building bricks within a limited playing field and then stack them in order to build up a tower of maximum height. The project itself is organized in three sequential project stages focusing on (1) the strategy map out, (2) the mechatronic conceptualization and (3) the realization and performance tests. This project-based learning concept is designed and carried out from two different departments – the department of mechanical engineering and the department of electrical engineering.
The key concept of cooperation-focused education bases on the idea that – for the final succeeding – two groups have to work together very closely as one team. Due to this, the project task further considers the condition that the developed solution of two cooperating groups should act in concert to achieve the goal of building a tower as high as possible, i.e. an imaginable strategy might be to separate the process of brick collecting from that of brick stacking and consequently develop two vehicles, which are optimized for their respective process individually. Thus, each group is responsible for its own subsystem, but to achieve the shared goal, the team has to continuously discuss, negotiate and decide about the requirements and constraints for the overall system resulting from their jointly pursued strategy.
The paper introduces the details of cooperation-focused education in mechatronic engineering and reflects the key concept with reference to publications of comparable projected-based learning approaches. It further gives an account of the pilot studies' results and discusses them in regard to the expected educational objectives.

2 COLLABORATION AND COOPERATION IN EDUCATION

2.1 Collaborative Learning

Collaborative learning is an umbrella term for a variety of educational approaches involving the joint of intellectual effort [1]. It is usually realized by project work, in which students mutually searching for understanding and solution of shared tasks or problems. Collaborative learning is built on negotiation and discussion, in which the participants can present and argue their ideas using rational reasoning. Dillenbourg [2] describes that collaborative learning requires a corresponding learning situation that is defined by a certain degree of symmetry regarding the following aspects:

- Symmetry of action: each participant should be allowed to perform the same actions as any other within the group;
- Symmetry of knowledge: all participant should possess the same level of knowledge and should be equally skilled;
- Symmetry of status: the participants should be all of equal status, i.e. they should be on a same hierarchical and functional level.

A high degree of symmetry leads to very homogeneous project teams. Consequently, the participants often share the same motivation and goals from the beginning and they are able to support each other in training and reflecting disciplinary learning contents. Due to this, project-based learning has become nowadays the most favoured pedagogical model in universities, which is most commonly implemented in form of cornerstone courses (first year courses) as well as capstone courses (final year courses) [3]. However, mechatronic education is naturally less symmetric than disciplinary education. Mechatronics is not simply a blend of mechanical, electrical and software engineering, mechatronics has come to mean the synergetic usage of precision engineering, control theory, computer science and sensor/actuator technology to design improved products and processes [4]. Thus, in mechatronic education students should learn how to closely cooperate by using their complementary knowledge and skills.

2.2 Cooperation-Focused Education

Cooperation-focused education is a project-based learning approach especially for mechatronic engineering courses. It is part of the Karlsruhe Education Model for Product Development (KaLeP) [5], which emphasizes the particular importance of project work in a realistic environment to enable engineering key competencies. Cooperation-focused education further includes the simultaneous consideration of (1) cross-disciplinary synergy, (2) disciplinary balance and (3) industrial relevance.

Cross-disciplinary synergy contains the understanding that mechatronic system design is more than an assembly of mechanical, electrical and software components. Its key value is attached in the integration of these classical disciplines. Grimheden [6] concludes his research in mechatronic engineering education by the following statement: 'to be mechatronic is to be synergetic and to be synergetic generally demands expertise in all underlying subjects'. Thus, mechatronic education has to assure shared knowledge of the fundamentals of mechanical, electrical and software as well as their basic interdependencies. This is what enables cross-disciplinary communication and mutual understanding, and thus allows the synergetic application of complementary competencies.

Disciplinary balance addresses the equally consideration of mechanical, electrical and software learning contents in both theoretical and practical education units. Mechatronic courses are still often led by a department assigned to one of the classical disciplines. Consequently the integrated project work is often dominated by discipline-specific methods, tools or techniques, which is counteracting the concept of cross-disciplinary synergy. Nevertheless, in literature several mechatronic education projects have exemplary presented how the balance between different disciplines can be successfully realized (e.g. Saleem et al. [7]).

Industrial relevance emphasizes the importance of the fact that mechatronic education has to qualify students for their future profession. Due to this, education always has to be geared to the requirements in industrial practices. In this context Matthiesen [8] states that especially the fulfilment of the function in a cost-effective way – from the customer's point of view – is the main selling criterion of any product. Consequently students have to learn how to identify the relevant functions of mechatronic products, how to synthesize, i.e. how to prethink and document the embodiment fulfilling these functions and finally how to validate the function fulfilment quantitatively and qualitatively [9].

3 ELEMENTS OF THE APPROACH COOPERATION-FOCUSED EDUCATION

This section describes how the three components of the cooperation-focused education approach can be realized within the project work of an undergraduate mechatronic course. The presented model of a project work allows students to apply the knowledge gain by lectures and to expand it by cooperation experiences and project management skills.

3.1 Industrial relevance

An important part of academic classes is to get experience in an industry-oriented working environment. In order to establish this environment the students learn team organization, working in a team and get access to development tools such as Matlab Simulink, ProEngineer and 3D-printers. For learning and feel the problems of team organization, the 100 participated students are subdivided into 20 groups with 5 persons each. Two groups have to work together very closely as one team to fulfil the task. These two teams are located in different building, like usually in industry to make the communication a little bit more difficult.

Furthermore the project is managed by a stage-gate-process. The project is subdivided into four stages. In the first stage the students have to develop a strategy to fulfil the task, estimate the maximum available points and identify weak points. In the second stage they have to generate alternative ideas and evaluate these by analyzing their pros and cons. This is followed by the third stage, the concept stage, which includes detailed design space estimation and the validation of identified critical points by virtual and physical prototypes. In the fourth stage the students have to design their systems in detail. The completion of this course involves a final event, at which the student teams present their project results (strategy, mechatronic problems and ideas) as well as the prototypic realization of their final design. In a final competition including a performance test the student teams can compare their strategies, their designs and the corresponding prototypes.

3.2 Cross-disciplinary synergy

The second component of cooperation-focused design is cross-disciplinary synergy. This requires the cooperative integration of the three disciplines mechanical, electrical and software engineering. Consequently mechatronic engineers have to be trained in all of these disciplines. They are to be seen as unifying knowledge providers that are able to connect the experience of disciplinary persons or groups. Due to this it is of particular importance that mechatronic students – in addition to professional competencies – also acquire communication competencies improving their ability to discuss, negotiate and decide across disciplines.

The project work presented in this section allows students to learn these cooperation competencies in the context of mechatronic education. For this purpose the 100 participated students are subdivided into 20 groups with 5 persons each. The design task assigned to the groups is too complex to be solved by one group. Thus two groups have to work cooperatively together as a team to design and to realize successful cross-disciplinary solutions. As illustrated in Figure 1, each group is responsible for the design of one subsystem including its objectives, requirements and constraints. Both subsystems are indispensable parts of the overall system and necessary to fulfil the overall objective. In an industrial projects there are a lot of this subsystems caused by e.g. different departments or responsibilities. The complete team has to cooperatively discuss the problems appearing, make decisions across disciplines and adjust their subsystems for the best possible fulfilment of the overall function.

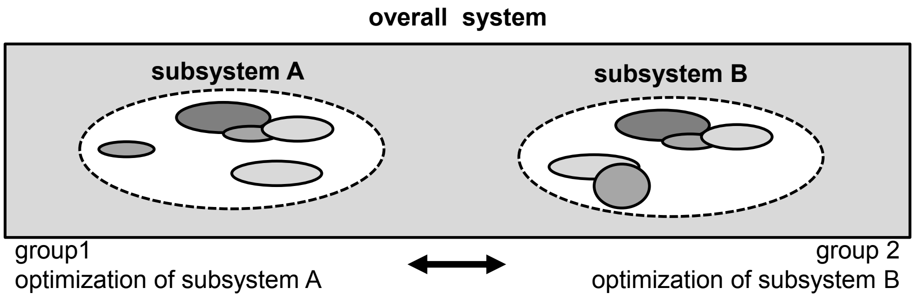

Figure 1. Design of the overall system and optimization each of the groups subsystem

3.3 Disciplinary balance

The third component of cooperative education considers the balance of the disciplines. The learning contents of mechanical, electrical and software engineering have to be equally weighted and linked by a mechatronic problem. A mechatronic problem is a development task that can only be solved by cooperative solutions. In doing so, the students should directly experience the synergetic potential of solutions that integrate all three disciplines in a balanced way.

The task assigned in the project work considers the development of a mechatronic system that should be able to automatically identify and collect building bricks within a limited playing field and then stack them in order to build up a tower of maximum height (cf. figure 2). Each team consisting of cooperative groups has to develop two subsystems working in concert to achieve the maximum performance, which is evaluated by awarded points. The total points are summed as a combination of the required time and the height of the tower. In order to achieve as many points as possible, it may be advantageous that the two systems are specialized. For example one vehicle is specialized for collecting bricks and the other for building the tower.

The mechatronic problems of this task depend on the single design concepts, but there are previously identified mechatronic problems all students have to solve during their project. These are (1) the slip compensation on the drive train, (2) the detection and transportation of the bricks and especially (3) the mutual communication between the two vehicles.

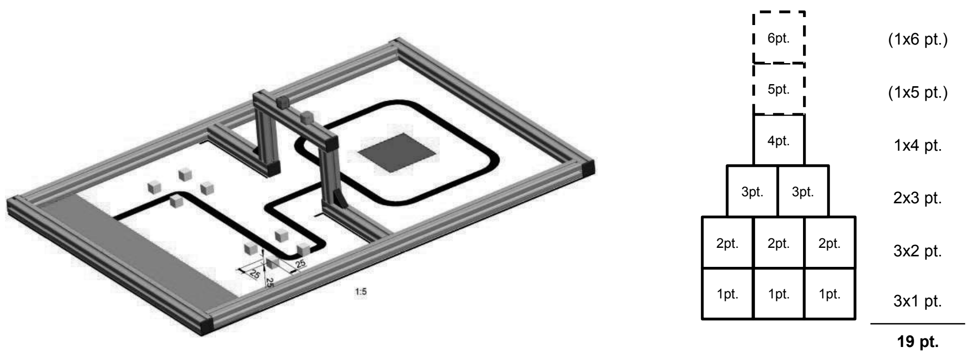

Figure 2. a) court for tower builder, b) example of a tower and total points

In order to limit the costs of the needed building material and to avoid re-buying only a limited amount of parts is available. The majority of these parts come from Fischertechnik computing systems. For such a task Fischertechnik seems to be an appropriate platform, because the parts can be mounted and adjusted very easily by sliding connectors and there is a variety of standard components available. The student teams are equipped by the following parts: several design elements, electric motors (with and without encoder), gears, gear racks, sensors (ultrasonic sensor, colour sensor, line sensor and IR receiver). If required the teams can design additional components by application of a 3D laser printer. The programming is done via a microcontroller supported by Matlab Simulink. With these standard components adequate reusability and a reasonable design freedom is achieved.

4 EVALUATION

In order to evaluate the educational concept a first cooperative mechatronic project has been analyzed in a pilot study. This study considered (1) the identification of weaknesses, (2) the determination of necessary components and (3) the level of the students' workload. Due to this four students have dealt extensively with the task. A multidisciplinary team with two students of mechanical engineering and two of electrical engineering pass through the first three project stages. As illustrated in Figure 3 the students designed two different concepts that have been worked out in detail and realized as prototypes.

Cooperative solution 1- crane with hopper vehicle: In this concept a tower of maximum height (1x10) and the maximum number of points was built. In this case the students consciously accepted the penalty for a timeout. The crane runs along the border construction and picks up the bricks. In the meantime the hopper vehicle moves into the construction sector. The crane places all the bricks in the

hopper car. As soon as all bricks are stacked, the hopper opens and releases the tower. Then both vehicles move back to the starting area.
Cooperative solution 2 – Caterpillar with shovel vehicle: This concept pursued a more defensive strategy than the crane. The team builds a more stable tower (2x4) very quickly to achieve the time bonus. In order to do this two vehicles are used a caterpillar and a shovel vehicle. The caterpillar pushes the cubes together at the right band. The shovel vehicle picks up all bricks at once, moves to the construction area, turns the shovel and places the tower on the ground.

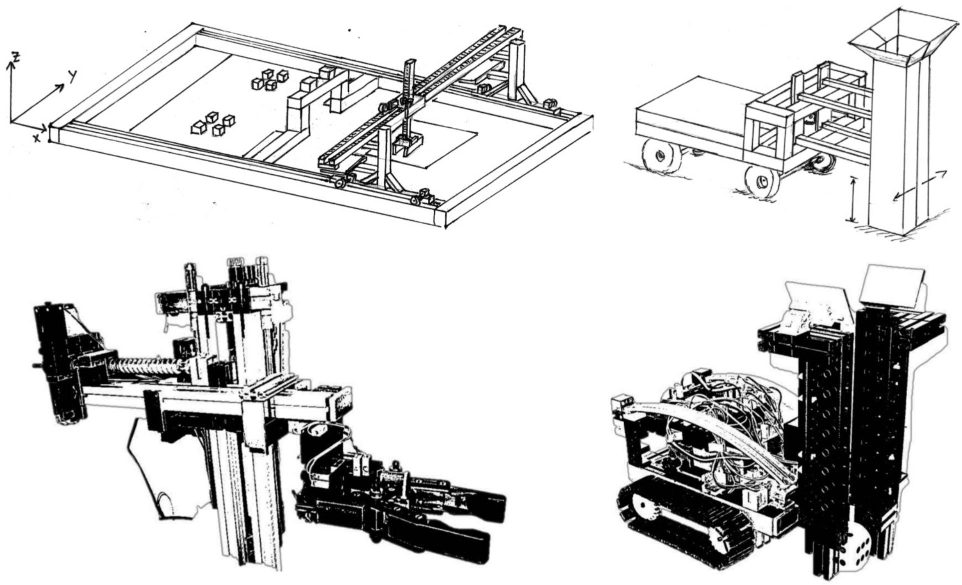

Figure 3. Gantry crane (left) with cone car, concept sketches (above), prototype models (bottom)

This pilot study – conducted with four students at a similar level of knowledge representing the target group of mechatronics students – was a very important step for the improvement of the project realization. Based on the findings some weaknesses of the task could be identified and already be fixed. Furthermore the number of required components for different concepts could be determined and the workload of students was estimated to 3-5 hours per week.

5 CONCLUSION

This paper introduces the concept of cooperation-focused education, which is a project-based learning approach for mechatronic engineering courses especially emphasizing the three components (1) cross-disciplinary synergy, (2) disciplinary balance and (3) industrial relevance. Cooperation-focused education includes the understanding that that mechatronic system design is more than an assembly of mechanical, electrical and software components and that its key value is attached in the integration of these classical disciplines. In order to enable this potential mechatronic students have to be especially trained in cross-disciplinary communication. In this context it seems to be important to teach mechatronic with equally consideration of mechanical, electrical and software learning contents. Disciplinary balance enables mechatronic students to evaluate and to improve integrated solutions with a view on the best fulfilment of the overall function in a cost-effective way. Mechatronic education has to be geared to these requirements and allow students early to experience cooperative project work in order to enable the required competencies.
In further papers the educational concept will be extended by a more intensive consideration of cost and production aspects, competence measurement and SysML teaching concepts. The students have to become aware of costs and resources as well as of the impact of their design on manufacture and assembly. These aspects – transferred to project work by e.g. team budgets and limited prototyping resources – will intensify the understanding for the importance and the necessity of cooperative engineering design. Furthermore a concept of competence measurement to identify the individually

strength and weaknesses in one of the three competence dimensions will be introduced. So should it be possible to improve the student's individual skills. One more very important skill for mechatronic students is the ability of a unified language for different disciplines. Therefore SysML will be used from the beginning of the course until the in two pieces divided exam.

REFERENCES

[1] Smith B.L. and MacGregor J.T. What is Collaborative Learning? In Goodsell A. et al. (Eds.) *Collaborative Learning: A Sourcebook for Higher Education*, Pennsylvania, 1992.

[2] Dillenbourg P. What do you mean by 'collaborative learning'? In Dillenbourg P. (Ed.) *Collaborative-learning: Cognitive and Computational Approaches*, Elsevier, Oxford, 1999, pp.1-19.

[3] Dym C.L., Agogino A.M., Eris O.,Frey D.D. and Leifer L.J. Engineering Design Thinking, Teaching , and Learning. In *Journal of Engineering Education*, Vol.94, No.1, 2005, pp.103-120.

[4] Erkmen A.M., Tsubouchi T. and Murphy R. Mechatronics Education. In *IEEE Robotics and Automation Magazine*, Vol.8, No.2, pp.4, 2001.

[5] Albers A., Burkardt N. and Meboldt M. The Karlsruhe Education Model for Product Development "KaLeP" in Higher Education. In *International Design Conference DESIGN 2006*, Dubrovnik, Croatia.

[6] Grimheden M. *Mechatronics Engineering Education.* Doctoral Thesis, Stockholm, Sweden, 2006.

[7] Saleem A., Tutunji T. and Al-Sharif L. Mechatronic System Design Course for Undergrate Programmes. In *European Journal of Engineering Education*, Vol.36, No.4, 2011, pp.341-356.

[8] Matthiesen S. Seven Years of Product Development in Industry – Experiences and Requirements for Supporting Engineering Design with 'Thinking Tools'. In *International Conference on Engineering Design, ICED'11*, Copenhagen, Denmark.

[9] Meboldt M., Matthiesen S. and Lohmeyer Q. The Dilemma of Managing Iterations in Time-to-market Development Processes. In *International Workshop on Modelling and Management of Engineering Processes MMEP 2012*, Cambridge, UK.