PROBLEM-BASED TEACHING IN MECHANICAL ENGINEERING DESIGN – A COLLABORATIVE COURSE MODEL

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ABSTRACT
This paper deals with a new approach for problem-based teaching that has been developed to meet the needs of today's industry. After giving a definition of problem-based teaching against the background of project-based teaching, the implementation of student-centred teaching by combining two Master's courses is being described. One course deals with managing and planning Virtual Product Creation Processes. In the other course students have to develop a product from the first idea to a virtual prototype. Benefits of problem-based teaching as well as current challenges are explained.

Keywords: Problem-based teaching, IT support, design projects, collaboration, interdisciplinarity

1 INTRODUCTION

The formal engineering education has a long tradition. L`École Politechnique established in France in the late 18th century marks the beginning [1]. Ever since engineering schools were established all over the world due to societal needs and technological developments. Especially in the 20th century engineering education underwent significant enhancements concerning quality and subject matters. Since the second half of the 20th century improvements in information technology had a major influence on the education of an engineer. Computer Aided Design (CAD), Computer Aided Manufacturing (CAM) as well as Product Lifecycle Management (PLM) are only some examples of solutions developed for product modelling, production planning and engineering collaboration. To keep up with today´s and tomorrow's industry needs, engineering schools are required to implement and teach such solutions (Figure 1). Additionally, in today's globalizing world with its fast growing technologies the industry expects novice engineers being competent in the use of technical and methodological knowledge as well as having interdisciplinary skills. The interdisciplinary challenges comprise soft skills and communication skills, such as the capability to work in a team, to make decisions and to interact with other disciplines and with management. Academic programme coordinators realised that interdisciplinary skills cannot be gained following a traditional curriculum, where solely methods or formulas are taught. Particularly lecture based methods, large classes and single disciplines determine the early years of engineering studies. From an industrial point of view, graduated engineers are expected to be able to cope with the aforementioned needs and skills. This requires a further rethinking and restructuring of engineering education methods. Otherwise new engineering design education will lack deployment in industrial practice and finally fail.
Considering these facts a new approach has been developed by combining two courses and making them interdependent on each other. Following the problem statement (and the definition of today's challenges), problem-based teaching and its characteristics are defined and described in this paper. Furthermore, the new course model based on the new principles and the experiences from three years of execution are presented.

2 PROBLEM STATEMENT

Sullivan R., Sullivan J. M. and Mannix [2] discuss in their publication titled *Rethinking the Role of Education in the Life of the Professional Engineer* two different dimensions of engineering education. One dimension is of organisational structure and addresses the curriculum and pursues the student's need of earning a specified amount of credit points in a short period of time to get an academic degree. The programme administration is in charge of building up the organisational structure of the curriculum (Figure 1). In addition, students have to coordinate their studies out of the offered courses. The other dimension deals with the content and the quality of the courses. Although the programme administration organises the curriculum, the single course administrations are in charge of planning the course content.

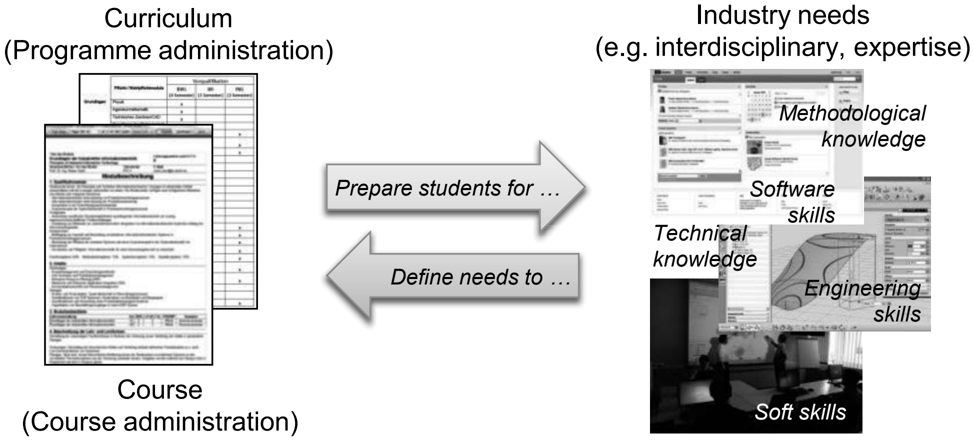

Figure 1. Interplay of industrial needs, curriculums and courses

As mentioned in the introduction, more complex skills are demanded from novice engineers in industrial practice nowadays. Completing a set of courses, earning the necessary credit points and getting the academic degree of an engineer do not fulfil the needs of today's engineering companies. Both of the mentioned dimensions should be taken into account designing a curriculum and courses. In the field of mechanical engineering, especially throughout the entire product creation process (PCP), the expectations of the industry are growing rapidly.

Durmusoglu and Barczak [3] state *"In a new product development process a new product idea moves through a series of activities from inception to launch. Gates at the end of a subset of activities serve as critical go/no go decision points"*. PCP has to consider all phases of the product lifecycle to satisfy the stakeholder's needs. Traditionally, the outcome of the PCP is evaluated on the dimensions time, cost and quality. Since global demands are growing substantially to achieve energy efficient and sustainable added value along the entire product lifecycle, products and services have to be sustainable without compromising the traditional success factors [4].

Another challenge is the complexity of today's products which contain a certain number of parts or components from different supplying companies. The coordination and management of the product data generated during the development and production is playing a crucial role in the success of PCPs [5]. In addition, increasingly more experts from different disciplines such as mechanical engineers, electrical and electronics engineers, mechatronics engineers, environmental engineers, industrial engineers etc. are working together along today's PCPs. Therefore, further actors and stakeholders like original equipment manufacturers (OEM), suppliers or engineering service providers should also be taken into account for a properly designed and managed PCP.

As a result, a rethinking of engineering and product design education is inevitable. Modern education has to enable and qualify the engineers to meet the needs of the industry equally to global challenges. Due to time restrictions of Bachelor and Master Programmes it is hardly possible to add more courses to the curriculum addressing the mentioned problems and challenges. Therefore, a higher effectiveness level should be considered within the existing courses. Studies have shown that the highest learning effectiveness level can be reached by participating, doing and making own decisions (cp. [6]). Implementing a teaching concept where the students make an expedient contribution to the course outcome should be the aim modern education.

3 GENERAL APPROACH

Case studies are an increasingly popular way of teaching. A case study is considered as a student centred activity that involves the study of a topic which raises issues or problems for analysis. They can be classified mainly into two categories: (1) *Project-based teaching model* and (2) *Problem-based teaching model*. These models can be defined and differentiated as follows (cp. [7]):

(1) *Project-based teaching model* is a task oriented teaching method to solve defined problems. The activities or methods to be used are defined by the trainer of the course and the students have to produce a solution to overcome the challenges. The trainer plays the role of a *supervisor* and the students do not have the freedom to make decisions on their own. The outcome is usually determined.

(2) *Problem-based teaching model* differs from the *project-based teaching model* by the attitude of the trainer who defines the problem and transfers necessary knowledge. The trainer plays the role of an *adviser*. As a result the students determine which methods they use and they are forced to make decisions on their own. In contrast to (1) the outcome can be either open or determined.

Considering one of the most effective learning methods it can be concluded that *problem-based teaching* with an open outcome is the most effective way of transferring knowledge and, from a student's perspective, taking on responsibility.

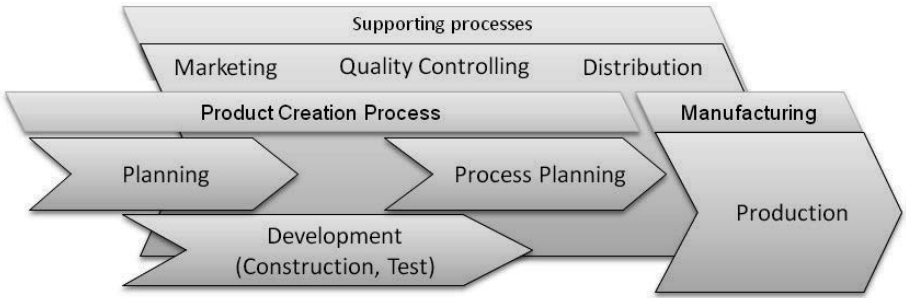

Figure 2. Outline of major product creation process phases

Figure 2 shows a PCP divided into certain activities. The PCP itself is a sequential process with overlapping phases and many iterative loops covering all phases from the first product idea to the start of production. Marketing, quality control and distribution are, for instance, directly linked to the PCP as supporting processes. While engineering design courses have an inherent affinity to project work and an open solution space, courses in the field of supporting processes are usually based on specific fictional or non-fictional case studies. To increase the learning effectiveness a shift from case studies to a project situation can be supportive. In order to address the described challenges a new approach is proposed in this paper. Combinations of different university courses are seen as a potential for overcoming the current barriers of teaching regarding problem-orientation.

4 A COLLABORATIVE COURSE MODEL

The School of Mechanical Engineering and Transportation Systems at Technische Universität Berlin offers a variety of courses for both Bachelor and Master Programmes. The portfolio of courses was developed in order to offer a multi-dimensional view of today's and tomorrow's industrial needs including Information Technology (IT) support for CAx systems and collaboration as well as engineering methods and processes. This paper focuses on two courses, *Applied Industrial Information Technologies* (AIIT) and *Development and Management of Digital Product Creation Processes* (DPCP). These two courses are running parallel during winter term since 2008. Both courses are described with particular emphasis on their integrative character.

4.1 Applied Industrial Information Technologies

The fundamental concept of this course is to focus a *problem-based teaching* approach complementary to traditional engineering education. The basic idea of this course is developing a product from the concept stage to a virtual prototype. The primary aim of this project is to offer Bachelor and Master students a practical experience in dealing with different IT-systems in the context of an actual design task. Basic knowledge about Virtual Product Creation, e.g. Computer-aided Design (CAD) and Computer-aided Engineering (CAE) tools, gained in fundamental courses is a prerequisite. In addition to trainings of different engineering IT systems, supporting group work, e.g. groupware and collaborative virtual environments, and design methodology are introduced in order to facilitate a logical and well-structured product creation process.

The design task, usually situated in the field of sustainable mobility, creates the basic frame throughout the entire course. The only constraint set by the trainers is a stage gate control process (cp. [3]) by means of Design Reviews which are distributed over the course period. These reviews reflect the current design progress. They also serve as a basis for grading the students. Between these regular reviews the students can act unrestricted to a certain extent. Additionally, weekly round tables give the students the opportunity to discuss their progress with the trainers and ask for advice. The trainers create engineering change requests in order to create a more realistic and dynamic industrial scenario. The trainers are required to observe the progress of every team during the entire project in order to mentor the students during the mentioned round tables and design reviews. As a response to the demands on tomorrow's engineers, project teams are set-up. The teams consist of four to six students from different disciplines like mechanical engineering, computer science or industrial engineering. Aside from designing a product a business plan involving marketing and cost issues has to be developed. This interdisciplinary approach enables a wider solution space and increases the awareness of different disciplines.

4.2 Development and Management of Digital Product Creation Processes

Contrasting to the above described project the Masters course DPCP has a strong focus on the holistic view of engineering processes and methods within the Virtual Product Creation. The primary aim is to understand how a successful project is conducted and how IT can support the various processes. Basic project management concepts like Gantt-Charts or Key Performance Indicators (KPI) are introduced. Additionally, tools for Product Lifecycle Management (PLM) and Business Process Management (BPM) are taught. BPM is used to develop *Best Practices* and guidelines for organisational and management issues, i.e. approval or change processes. The importance of these process models in the context of PLM systems is also highlighted. Various soft skills, i.e. moderation, team leading and negotiation etc.), are experienced. The DCPC teams consist of two students from mechanical engineering and production technology.

4.3 Combined Course Concept

The main concept is to combine the two courses AIIT and DPCP to meet the demands of a *problem-based teaching model* with an open outcome. Figure 3 illustrates the collaborative teamwork of the participants of these courses. The DPCP teams become part of the AIIT teams. One DPCP student has the role of a project manager. This student is in charge of implementing the theoretical knowledge gained in lectures through planning and control of the engineering process. The project manager undertakes managerial tasks regarding coordination and organisation, such as project planning and defining *Best Practices*. The other student is in position of a process observer. That means observing and monitoring the actions which are actually performed.

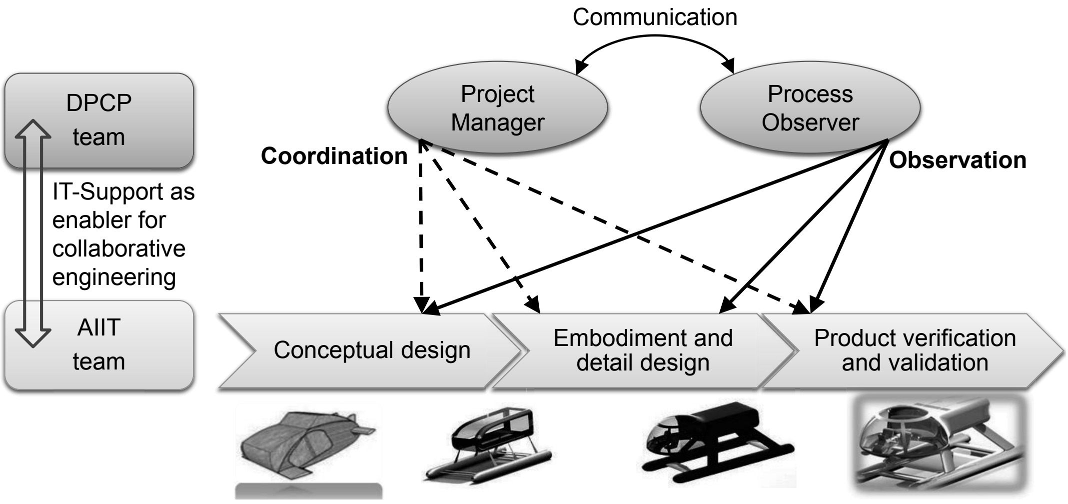

Figure 3. Cooperation model of two Master courses (DPCP and AIIT)

Consequently, a permanent reconciliation of the initial project plan with the current project progress is necessary. The process observer compares processes defined by the project manager with the actual processes. Therefore, the process observer needs to collect data about the project performance of the

AIIT team. Questionnaires regarding pre-defined KPI such as invested time, milestone achievement, presence in team meetings, allocation of tasks and communication effort are distributed to the AIIT teams weekly. Finally, the data needs to be evaluated and the most promising factors for a successful PCP can be derived. Figure 4 exemplarily shows the evaluation of the KPI *Communication effort*. This KPI measures the quantity of communication activities within the AIIT team and can be interpreted as part of the actual student's workload. It involves any kind of communication activities, e.g. writing e-mails, making phone calls, meeting face-to-face and meeting online. The communication effort increases as the Design Reviews and round tables draw near. The remarkable peak towards the final presentation shows how drastically the workload at the end of a project increases.

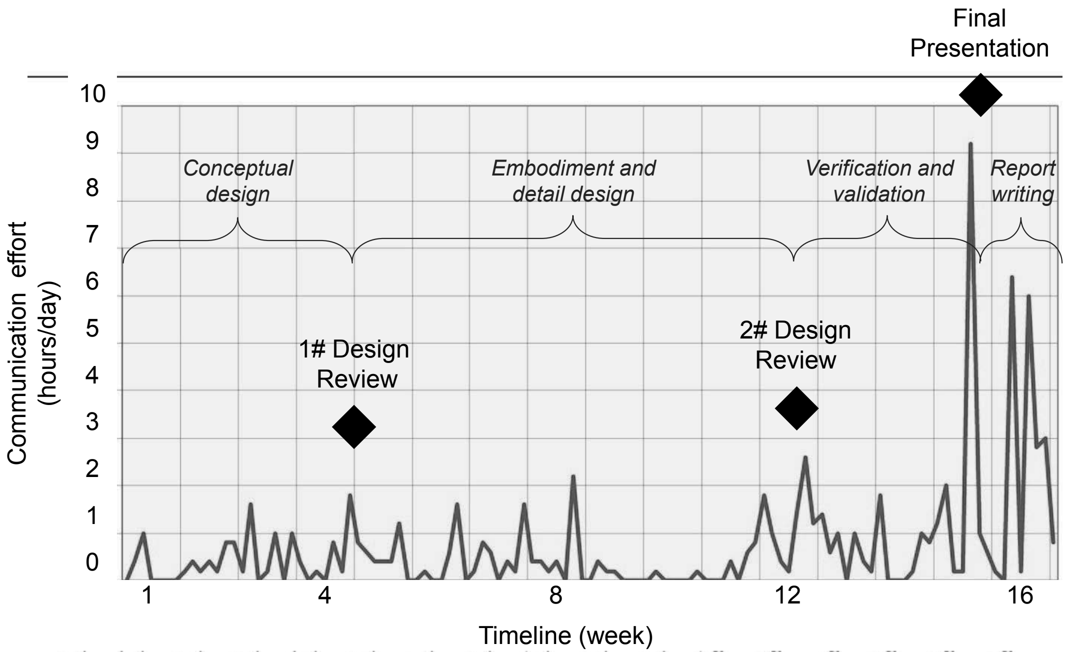

Figure 4. Communication effort of AIIT team observed by DCPC team

The feedback from the AIIT teams plays a crucial role for the outcome of the DPCP team. On the other hand, the project manager's performance influences the outcome of the design teams. To enable a better communication between the students an Internet based collaboration tool, provided by the course administration, is used. The basic functions of the tool are document sharing, forums and wikis. Social network functions are also included. Users can see who is online and have the possibility to get directly in touch via messaging. Additionally, Video Conferencing is provided. That way, the students have the possibility to meet online 24/7 to discuss their design progress.

The proposed concept addresses the challenges in modern engineering education. The communication between two teams is arranged according to the *problem-based teaching model* as the interaction to the course administration is only limited to Design Reviews and round tables. The DPCP team decides how to manage the AIIT design process. Depending on the attitude and management approach of the DPCP team they experience different reactions and face different problems. Solutions and decisions regarding these problems are discussed with the course administration since their decisions influence the outcome of the design project. The problem-based nature of both courses let the students experience dynamic and more realistic project work. That way, engineers improve their soft skills and meet the demands of the industry.

5 CONCLUSION

A common practice in engineering education courses is the application of theoretical knowledge about methods and tools on case studies coming from industrial practice or fiction. The problem of this way of teaching is the missing "interactivity". Within this teaching concept, tasks and solutions are pre-defined and there is only little possibility to influence the outcome from a student's perspective. In order to receive a higher learning effectiveness and feedback on individual actions and decisions a more dynamic project situation is beneficial. Since the outcome can be influenced it leads to a higher motivation of the students in contrast to an artificial problem statement. Positive feedback from the students has shown that they feel more motivated if they are allowed to make decisions on their own. Eventually, the students appreciate the course model.

The paper describes the benefits of *problem-based teaching* on the example of a combined course model. Planning and management of design processes are integrated into the execution of a design project. In particular design projects can be used as a platform to integrate several disciplines. The complex coordination of their work requires an increased communication effort and leads to an awareness about all kinds of interface problems like IT integration, different methods used by different disciplines and even social behaviours of the project members. Students learn how their decisions impact the outcome of a design project.

Along with the benefits the following challenges were perceived and experienced by the course administration since the winter term 2008:

- Although the participants of these courses have to work together they are graded separately according to different expectations and criteria. This creates another challenge for the course administration since both courses depend on each other.
- Another challenge for the course administration was recognised during the last years. The number of students who participate in both courses varied and accordingly the manager/engineer ratio. With regard to a balanced ratio a constant number of students in both courses is necessary.
- Additionally, it occurred that not every student is able to manage a student design project though the possibility to participate on DPCP is offered to all Master's students of the same programme. In some cases this has lead to some conflicts within the project team. In this case, the course administration was required to take action.
- According to the feedback from students a better and easier-to-use collaboration tool is necessary.

As a result of both the interdisciplinary structure of the AIIT course and the collaborative work between the two courses students need to think across traditional barriers. This offers the possibility to extend the approach. One example might be the combination with a quality control course. Students can validate a design regarding quality issues with methods like Quality Function Deployment (QFD) or Failure Mode Effects Analysis (FMEA). Changes to the design can be proposed and the awareness of the project team can be raised. This idea can also be extended by combining two courses within the Product Creation Process, i.e. the combination of engineering design with manufacturing planning. There is a trend to decrease the overall time-to-market by conducting planning activities parallel to engineering tasks. The Simultaneous Engineering approach demands a high amount of communication effort between engineers of both fields and needs to be practiced already in university's environment rather than gaining this experience in industrial practice after graduation. These are only two examples of how different courses can benefit from each other. Creating a win-win situation by extending the learning experience without investing more resources is possible in modern engineering education.

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