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# HOW TO SET UP STUDENT PROJECTS WITHIN COLLABORATIVE RESEARCH PROJECTS

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**ABSTRACT**
The opportunity of designing real products within the course of studies is of great significance for students in mechanical engineering, as they can apply their knowledge attained in lectures. For that reason the Institute of Product Development at the Technische Universität München offers product development seminars. The goal of the seminar is to give the participants an impression of how a product is designed, whereas the scope of the course spans from analysing the market conditions, setting goals, identifying requirements, and creating of innovative new product concepts to prototyping the best solution. This work focuses on the question how to communicate the design task to students, allowing them to take up the problem without alluding to a solution at first. At the same time it has to be ensured that the outcome is suitable to be integrated directly into super-ordinate research projects.

*Keywords: Student project, engineering education, collaborative research, project-based learning*

## 1 INTRODUCTION

Engineering design education in mechanical engineering is often based on the curricular concept of lectures. Thus, students attain only theoretical knowledge of how to design products. In order to apply this knowledge practically and further gain experience in team collaboration student, projects are an important opportunity to extend engineering abilities.

For example Dutson et al. [1] mention capstone projects, which are conducted in student teams and function as the last step to complete the studies of mechanical engineering. They state that students are often highly motivated and have a great sense of responsibility if the design task is formulated by a partner in industry.

In this context, it is important to mention project-based learning and problem-based learning, as the students are working on predefined problems, i.e. design task, within their projects.

According to Blumenfeld et al. [2] project-based learning can be seen as a comprehensive perspective focused on teaching by engaging students in investigation. They summarize that students generate solutions to specifically designed problems by asking and refining questions, debating ideas, making predictions, designing plans and/or experiments, collecting and analyzing data, drawing conclusions, communicating their ideas and findings to others, asking new questions, and creating artefacts.

Problem-based learning focuses on enhancing the students' application of knowledge, problem solving, and self-directed learning skills. This is achieved by requiring them to actively articulate, understand, and solve problems [3].

Both approaches make use of collaborative student groups. In literature they are often used almost synonymously. Nevertheless, the approaches have slight differences. Both start with a problem that is to be solved by the students. But, while in problem-based learning the students' activity should be focused on ''studying'', in project-based learning the focus lies on constructing a product [4]. Thus, problem-based learning does not necessarily lead to the development of an end-product [4]. This is also emphasised by Blumenfeld et al. [2], who state that the characteristics of project-based learning is on the one hand the problem driving the activities, which results in a series of products. On the other hand these products culminate in a final product addressing the initial problem. According to Savery [5] within a project-based approach the desired end product is usually specified in the beginning and the students' learning process is primarily oriented in following correct procedures. Further he states, that teachers are more likely to be instructors and coaches (rather than tutors) providing expert

guidance. Thereby, the teaching is provided according to learner need and within the context of the project [5].
The aim of this paper is to discuss how a student design project can be set up in order to communicate the initial problem to the students in a way that allows them to take up the problem without alluding at solution at first. Thus, requirements for formulating the design task are to be stated. Thereby, the integration of student projects into long-term research projects will be taken into account. This integration affords the results of the student projects, that are suitable for a direct use in the super-ordinate research. It is to be discussed whether the principles from project- and problem-based learning can be used to define requirements for designing the initial problems of extracurricular student projects integrated into long-term research projects.
For that purpose the paper is structured as follows: Section 2 describes the general requirements for the design of problems. In Section 3 student projects are presented as they are currently offered at the Technische Universität München. Subsequently, the different circumstances of integrating student projects within long-term research projects are shown in section 4. Finally, section 5 covers the discussion of requirements for defining a problem for student projects within research projects and how the formulation of the design task can be supported.

## 2 WHAT ARE THE REQUIREMENTS FOR STUDENT PROJECTS?

In this section requirements for the setup of collaborative student projects are discussed, in order to achieve a maximum benefit for the students taking part in such projects.
For example Dutson et al. [1] state that a design project in engineering education should be challenging for participating students. At the same a successful solution should be attainable. Further, students should be able to access literature and other information pertaining to the project's topic. The participants should be aware that they have the possibility to apply their theoretical knowledge. Dutson et al. [1] also point out that engineering design work should be involved. For example meeting specified standards and safety criteria should be part of the design task. Success factors for student projects are described by Kreimeyer et al. [6]. These span - among others - from a clear definition of the roles of the different project participants - like students and tutors - the transparency of decisions, collective goals, the team configuration to feedback of the personal communication style and appearance.
The Accreditation Board for Engineering and Technology [7] states some requirements for engineering programs. This covers not only the attainment of the abilities to identify, formulate, and solve engineering problems, but also the abilities to design and conduct experiments. Further the abilities have to be fostered to analyze and interpret data and to design a system, a component, or a process in order to meet desired needs within realistic constraints. Finally, at the end of an engineering program the participants should be able to function on multidisciplinary teams and to communicate effectively.
The aspects described above can be seen as general requirements. They can serve as a guideline for setting up student projects. In fact, they only give a hint at how to communicate the design task to the students. Concerning the actual design of problems, contributions can be found in literature on problem-based learning. In contrast, there are hardly contributions explicitly focused on project-based learning.
As mentioned in section 1, both problem- and project-based learning start at a given problem. Furthermore, the two terms are not clearly separated. Thus the topic for the description of requirements for designing the starting problem is problem-based learning. These requirements are addressed by several authors and can be summarised as follows [8, 3, 5].
A problem has to be open ended; a possible solution must not be given. Further, it should be set up appropriately for those students who are expected to take part in the project. Although the students should be challenged, their prior knowledge and cognitive development has to be taken into consideration. The problem has to be ill-structured, which means that its goals are only vaguely defined and multiple solutions - as well as multiple solution paths - should be possible. The problems' constraints should not be stated from the start, as it is important that the students learn to explore and define the constraints by themselves. Jonassen and Hung [3] ask for a moderate degree of "structuredness". They define the latter as the intransparency, heterogeneity of possible interpretations, the dynamicity of the problem and the legitimacy of competing alternatives. This is closely related to the degree of a problems' complexity, which should not affect the students' motivation negatively.

A crucial point in the design of problems is to integrate collaborative aspects in the project. The students should have the opportunity to access the problem from multiple perspectives or disciplines. A further aspect regarding the students' interest is the authenticity of the project, e.g. it has to be adapted to the reality in industry. According to Jonassen and Hung [3] it is important to evaluate the difficulty of a problem, in order to design it appropriately for the students. For this purpose they introduced a model for the assessment a problem's difficulty. Therefore, they differentiate three types of problems: decision-making, diagnosis-solution and policy problems. Their difficulties can be characterized by the problems' complexity and "structuredness".
The difficulty of a problem can affect the students' motivation and interest in the problem, which are crucial for the project's success. Maufette et al. [9] state, that in order to reach a high capacity to acquire knowledge and an appropriate confidence level the following problem characteristics have to be regarded:

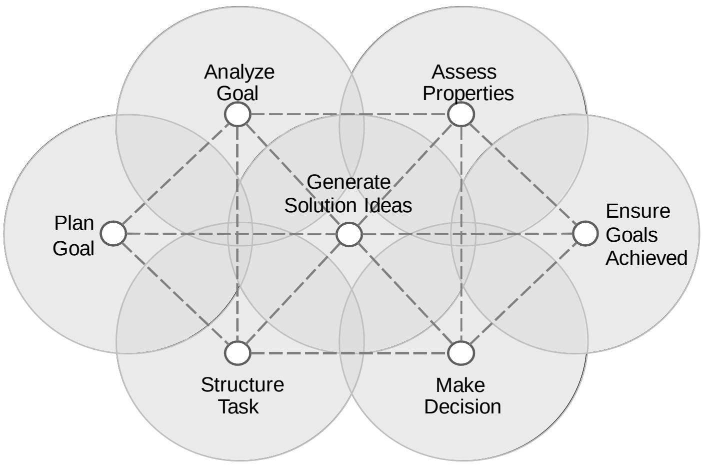
- Problem's value – perception of the task: the value for the student's later profession
- Competence level – self efficiency: prior knowledge of individuals, group dynamics
- Self-determination – perceived control: time-management, latitude

Hung [10] developed the 3C3R Model which serves as guideline to design problems in problem-based learning. The problems should consist of two classes of components, the core components and processing components. The 3C3R problem design model offers guiding questions for each of the components, in order to integrate them into the problem. The core components are content, context and connection of a problem. The processing components are tasks like researching, reasoning, and reflecting.
All of the approaches presented above cover the design of problems with the purpose of gaining a maximum of learning outcome for the students. The resulting solutions of those problems are not to be used directly within large collaborative research projects. Thus the requirements and guidelines described in the first sections can only form the basis for formulating the requirements of a design problem, which is used in a student design project integrated in a long-term research project.

## 3 PRODUCT DEVELOPMENT SEMINARS – AN OVERVIEW

As pointed out above, the possibility of enhancing engineering skills is of a high importance for students. The Institute of Product Development at the Technische Universitaät München offers product development seminars (PD-seminar) to enable students to use their knowledge - attained in lectures - in situations similar to real life. The goal of the seminar is to give the participants an impression of how a product is designed. Thereby, the scope of the course spans from analysing the market conditions, setting goals and identify requirements, creating of innovative new product concepts to prototyping the best solution. Throughout the course the participants are supervised by researchers in order to convey methodological knowledge [11]. The seminars are carried out in collaboration with partners in industry. A distinct design task is formulated with the purpose of systematically developing innovative and possibly unorthodox solutions[6]. Moreover, the students gain experience in working in an industry-like context [6]. As the design problem usually covers one specific product or a sub-unit of a larger system with specific, predefined interfaces, the project's constraints can be determined straightforwardly. The possible solution space should not be restricted unnecessarily. This is afforded in order to allow the students to work freely on the solution and to have the possibility of conducting all steps necessary the development process.
Within the student projects the Munich Procedural Model (MPM) [12] and the Munich Model of Product Concretization (MMPC) [13], as shown in figure 1, are on the one hand used as systematic guideline. It supports the student teams to find their way through the development process. On the other hand the students can practice and process the models and methods which are taught in lectures [11]. The MMPC represents the building and concretization of a solution space, starting at the stage of the model of requirements, the most abstract description of a product. This is transformed into a model of functions in order to be further transformed into a model of working elements. Finally, the latter is realized by modelling the physical components and their structure. The MPM with its seven steps - as depicted in figure 2 - delivers possible procedures and methods to reach the single model stages of the MMPC.
A motivating factor of product development seminars is that students are offered the possibility to work on a bachelor or master theses and German equivalents in the context of the seminar. A thesis' result should be a designed product, which is ready to be manufactured as a prototype.

The participants gain not only methodological knowledge and analytical skills, but also experience in designing in collaborative teams. Often many different disciplines are involved, e.g. mechanical and electrical engineers [11]. It is important that the students are capable of working independently and are willing not only to commit themselves within the project but also to take on responsibility for the seminar's outcome.



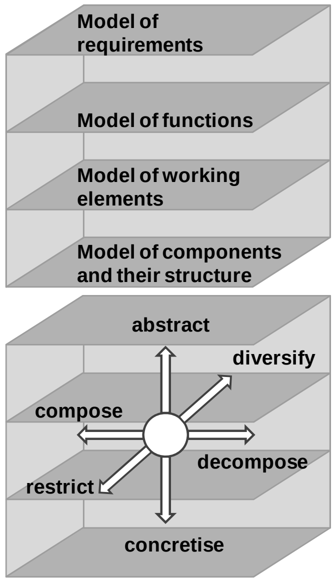




*Figure 1. a) Munich Procedural Model [12]; b) Munich Model of Product Concretization [13]*

## 4 SET UP OF A PD-SEMINAR WITHIN A LONG-TERM RESEARCH PROJECT

Other prerequisites, than described in section 3, can be found with a current collaborative research project. In this case, the product development seminar is to be integrated into a long-term research project, focusing on variant management in cooperation with a partner in industry. The regarded products are complex systems assembled of multiple smaller sub-systems, which are connected by various interfaces, see figure 2.

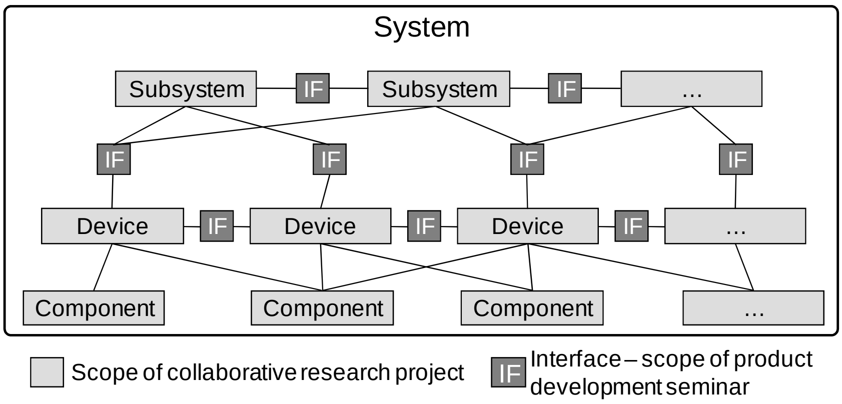



*Figure 2. Scope and structure of the collaborative research project*

Although the sub-systems are partly similar, the lack of standardisation is an important aspect leading to a high variance of subsystems. This high variance also results from a high number of different devices that form the subsystems. Finally the devices' components add up onto the high amount of possible system elements. The scope of the research project is to reduce and handle the product complexity by variant management. Thereby, the conflict between customer wishes – of internal customers within the company as well as of external customers – and the goal of standardization has to be taken into account. The methods, which are employed to reach these goals, are taken from the context of structural complexity management [14]. Matrix-based approaches are used to model, analyse and handle the dependencies within the regarded systems. These methods are analysed and evaluated upon their potentials and limiting factors in an industrial appliance, with the purpose of adapting and enhancing them. The system elements are to be standardized in two steps. First step is the standardization of functional parts of the devices, as different types of devices fulfil partly similar functions. The second step is to standardise the devices' housing. This is the point where the product development seminar is situated. In order to standardise the housings, the students' task is to standardise the design of the interfaces between the system elements on different levels of abstraction, e.g. the interfaces between two devices and the interfaces between a device and a subsystem. Thus, based on the defined interfaces, standardised housings can be designed. Successful seminar results are crucial for the outcome of the overall research project, as they are to be used as basis for further work.

## 5 PD-SEMINARS WITHIN RESEARCH PROJECTS - THE DESIGN TASK

Product development seminars are carried out in collaboration with a partner in industry. They offer students an opportunity to work on the design of a real product. The product or design task has to be defined in that way that the project spans through the whole product development process. Thereby, the supervising tutors convey methodological knowledge and skills to the seminar's participants. In the end, the students should gain knowledge about possible and necessary tasks in specific situations of the development process. The student team should be able to take up the design task as freely as possible, guided only by the most important constraints of the considered product. The students are expected to identify the detailed requirements by themselves.

Regarding the integration of a product development seminar the balance has to be found between communicating all requirements to the participants and naming only few constraints to let the students work independently. The former would ensure a feasible outcome to be integrated in the super-ordinate research project.

Concerning the requirements for the design of the initial problems in project- and problem-based learning, it can be seen that several of the requirements described in section 2 can be met by PD-seminars. As the seminar covers real products and is conducted in collaboration with a company, the design problems are considered to be ill-structured and authentic. Within the real project multiple solution paths are possible, although – in contrast to Savery's demand [5] – the constraints have to be defined up to a certain degree, as already mentioned. Thus, the projects cannot be designed entirely open-ended. A positive effect of naming the constraints is the limitation of the design task's difficulty and complexity. In the beginning of the project this information can serve as guideline to the students. Moreover, the collaborative projects have to be designed appropriately to the skills of the participants. This is reached by choosing students for participation, who have attended certain product development lectures.

In order to fulfil these requirements, some guiding aspects can be taken into account in addition to those stated by Kreimeyer et al. [6]. The first aspect is that the scope of the bachelor or master theses should not be limited to the design of products, but should include also the ones focusing on an analytical topic. Thus, the capacity for the elicitation of requirements by the students will be higher, which results in more reliable basis for the actual design of products. This effect can be enhanced by the tutors communicating important topics of requirements to the students. Such topics could be for example the identification of system configurations; identification of requirements concerning performance of the system elements and the reliability of interfaces; or the design for manufacturing concerning the interfaces. Each student should be assigned to a single topic. This way, every participant would gain knowledge in a specific area. With the intention of getting all the pieces of information the students need for their design and thesis, the students are forced to collaborate and gain experience in working with players of multiple disciplines. Moreover, it is recommended to allow the students to work directly within the company, in contrast to working at university facilities. It might be useful to point out sources of information in a company to the participants, in order to support the information acquisition. In the case of the current research project the students can work in the company, have access to data management systems and – most important – the possibility to ask questions as soon as they arise in order to access further information. Finally, regular meetings of students and tutors are crucial. They enable conveying methodological knowledge and supporting a systematic procedure.

## 6 CONCLUSION

In order to design the initial problem for a student project - carried out as product design seminar - the requirements for student projects as well as for problem- and project-based learning have been described. All those guidelines focus on stand-alone student projects.

An approach or guideline does not exist of how to design a problem for a student project, which is part of a super-ordinate research project. For that purpose, the constraints given by such a situation have been described and specific requirements stated. Finally, the latter have been discussed together with the requirements for stand-alone projects. Further, guiding aspects have been presented, which are applicable to set up a student project that is part of much bigger long-term research project. These instructions have been applied in the case of a current research project.

Although the guiding aspects have been helpful to describe the design task in the mentioned case, it is still to be proved how successful the initial problem formulation has been. Further work has to be conducted concerning the evaluation of the design task and validation of the guiding aspects. This is can be accomplished by requesting feedback from students concerning the design task, their motivation and how they perceived the work within the team. The results will be taken into account for refining the instructions, which will be used in forthcoming projects.

There is a final challenge to be met. Even if the students perceive the seminar as satisfying and are able to gain a maximum of further knowledge and engineering abilities, there is still no guaranty that the project's results are feasible for the use in the super-ordinate research project. Thus, the results of the current PD-seminar have to be a central input for the refinement of the guiding aspects.

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