EVALUATING LEARNING OUTCOMES OF SOFT SKILLS IN MECHANICAL ENGINEERING EDUCATION

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ABSTRACT
Soft skills, such as creativity, teamwork abilities and strength of implementation are essential key competencies for successful product development engineers. Within the structure of an engineer's academic education, design projects are applied as a medium to help develop professional, methodological and social competencies. At the Karlsruhe Institute of Technology (KIT) yearly events for undergraduate students (third and fourth semester) of mechanical engineering are organized, during which several hundred students are grouped into small project teams and work together to solve a common design task. During this design project, the students' progress in competence development is monitored in a total of six project milestones, the so-called workshops. In order to provide specific and purposeful feedback on the status quo of competency development, a five-dimensional competence model is used. The five dimensions are professional competence, methodological competence, creativity, teamwork abilities and strength of implementation. In this work a federal funded project with the aim of evaluating learning outcomes especially of soft skills in a reliable and valid manner is presented. Since the past two years of the research project several empirical investigations were made and led to specific tools which are currently under testing in the workshops. As a next step, these individual measures are to be integrated and enhanced in an Intervention Toolbox which is supposed to provide teaching personnel a set of instructions to create, analyze and interpret situations where students must show their soft skills.

Keywords: Project-Based Learning, Intervention Toolbox, Soft Skills Evaluation, Assessment

1 INTRODUCTION

Engineering education at universities is undergoing extensive changes towards teaching skills and competencies more than sheer knowledge. In order to develop suitable teaching models a proceeding investigation on mechanisms of competence-building is necessary. Having performed case-based education of engineering design students at the IPEK – Institute of Product Engineering over a long time, current trends like competence-oriented teaching are regarded as opportunities to investigate the basis why case-based education performs so well [1, 2].

In Germany, teaching engineering has always had a systematic relation to science as well as an equally important practical relevance. Both paths place a high demand on teaching strategies and learning outcomes. On the specialized scientific side, the subject matter is growing more demanding and requires more effective cognitive strategies. Whereas on the practical side, the challenges involve more methodological, social, collaborative and creative competencies [3, 4]. Therefore, the scientific field is due to assimilate a more operational and professional practice. One way to connect the two fields is to bring the engineering work into the education at a tertiary level.

2 KARLSRUHE EDUCATION MODEL FOR PRODUCT ENGINEERING

Since 1996 students of mechanical engineering at the IPEK – Institute of Product Development at the Karlsruhe Institute of Technology (KIT) undergo the KaLeP – Karlsruhe Education Model of Product Engineering [1]. The KaLeP is an integrated system for teaching product engineering skills. It consists of six basic elements, which form the core of each of the IPEK's courses (Figure 1).

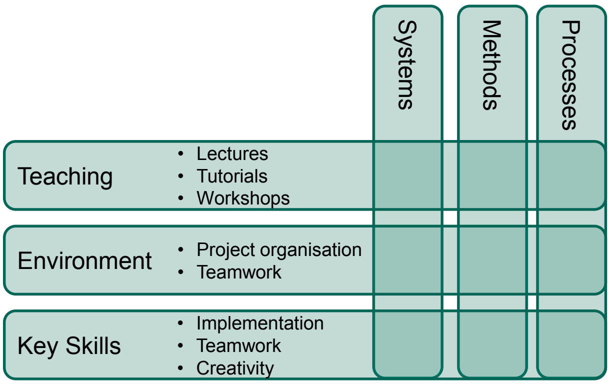

Figure 1. Integration Aspects

The three elements systems, methods and processes characterize different levels of detail in product development (Figure 1, on the left). Systems in this case means specific technical systems such as clutches, gearboxes or entire vehicles. Basic knowledge of technical systems is gained by the students mainly in lectures. A first step towards applying the knowledge to technical problems is made in tutorials. In order to develop competencies in product development, the students participate in an accompanying product development project. The development task is characterized by a certain complexity and uncertainty concerning the completeness of the task description. By applying methods of product development to their project task, the students learn how to systematically cope with these demands, develop creativity skills and improve their tolerance of frustration. Another very important aspect of the KaLeP is its focus on providing a realistic learning environment. Being organized in teams of five the students face certain difficulties when organizing their development project, defining work packages and preparing project milestones. Therefore the process aspect of product development as a sequence of problem solving activities in a team can be experienced by the students. Especially in the project milestones, the so called workshops, the development of key skills such as strength of implementation and teamwork competencies is fostered by giving specific feedback about the current level of competency development to the students. In the following the main focus will thus be laid on the undergraduate product development project work and the corresponding project workshops. Figure 2 shows such a workshop situation.

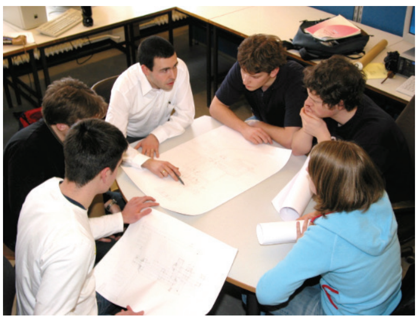

Figure 2. Workshop Situation with tutor and students

During the third and fourth semester the undergraduate students of mechanical engineering participate in a total of six workshops, each with a duration of four hours. During these workshops the milestone tasks and work packages are assessed and a feedback on the students' individual performance as well as the team performance are given.

The rating system with which this feedback is structured consists of five rating dimensions rated on an ordinal scale: professional competence, methodological competence, creativity, strength of implementation and the ability to work in a team (Figure 3). These dimensions allow an overall rating of competence profiles and are adapted to the specific learning arrangement from various sources [4, 5, 6, 7] and industry experiences [1, 3].

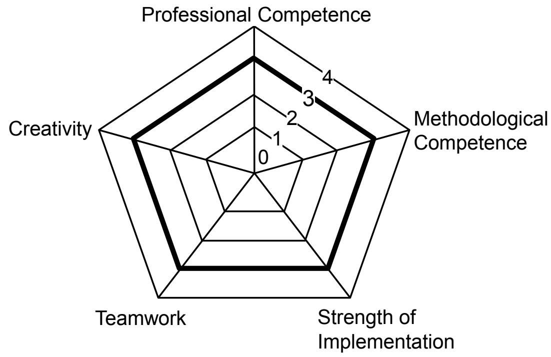

Figure 3. Five-Dimension Competence Model

In order to rate the students' state of competence development as reliable as possible, a corresponding description of the five dimensions was designed on the basis of empirical research data (table 1).

Table 1. Skill Sets and possible Interventions

Competence Dimension (weight)	**Indicators**
Professional Competence (5)	• Precise and correct answers to questions concerning lecture contents • Create neat technical drawings conforming to standards (Function, Form, Sealing-, Lubrication- and Mounting-concept) • Correct use of technical terms and proper technical design of models
Methodological Competence (5)	• Professional use of CAD o Structure of model, reasonable use of tools, no global interference • Organization and record keeping of project planning o Work packages, milestones, Gantt-Diagram • Decision making process needs to be documented o List of criteria, protocols of discussions, value-benefit-analysis • Supporting tools/software used in reasonable manner o e. g. Maple, FEM, Blender, MS Visio, etc. • Taking into account and illustrating the properties of the entire system o Production and maintenance costs, weight, etc.
Creativity (2)	• Generating unconventional solutions (comp. progress of the lecture) o Quality of ideas: general functioning and suitability to the problem • Ability to create a variety of ideas o Quantity of ideas: variety
Teamwork (2)	• Collaborative working inside and outside the project meetings o Project and resource planning, distribution of tasks, meetings • Clear communication within but also outside the team • Transparent depiction of procedures within the team and ability to perform as a team o Agreements, positions and tasks, organization of the group's work
Strength of Implementation (2)	• Presentation of ideas and solutions as a group towards others o Selling" of one´s ideas • Defending of one´s conceptions against other views and criticism o Objective arguing, adapting criticism in a constructive way • Brief depiction of localization of problems and selection of solutions o Procedure in making a decision (Advantages, Disadvantages)

Note that not all dimensions are weighted equally which is due to the focus on professional and methodological competences in basic engineering education. These key competencies go into the evaluation with the factor five whereas the other count in twice. Another important aspect is, that the dimensions are overlapping in some facets (e. g. project planning as facet of methodological competence and distribution of tasks as a facet of teamwork). The difference is in the main dimension to which the facets are assigned. In the given example this means, that regarding teamwork abilities the students should commit to a balanced workload planning where no team member has to work more than another. Regarding the Methodological competence dimension the committed project plan should be documented in an appropriate way in order to explain project progress, work packages and project structure to a third party. This overlapping requires the teaching staff to be trained to apply the competence model.

On the other hand this model allows to provide direct and specific feedback on the level of the students' competency acquisition and to give recommendations for suitable improvement actions (e. g. teambuilding, creativity techniques or steadfastness in the workshops) and thus enables the learners to continuously evolve their competence profile. In the end, the students become capable of developing complex products on the basis of requirement specifications. The race scooter in figure 4 is an example of a student team's project result from 2012.

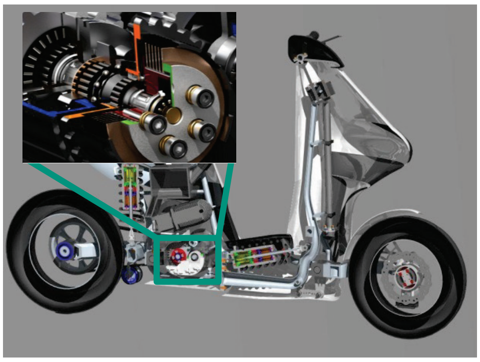

Figure 4. Student's Project Result – Race Scooter

3 SPECIFIC RESEARCH FOCUS

For many years, concepts of project work and learning, such as the KaLeP, have been implemented in university studies in engineering. Project topics and project work are orientated towards the engineering activity of professional practice and integrate into the university's technical theory curricula [8]. The complexity of the individual project tasks ensures students apply systematic and structured methods in order to solve the problems at hand. However, tasks within the engineering field are not comparable to mathematical problems, where the solution is either right or wrong, as product development tasks have various possible solutions. The difficulties lie on one hand within the evaluation of the learning outcomes for the different solutions, and on the other, the several interdisciplinary skills which the students achieve. Plus the competence model's facets have to be assessed in a rather strict way in order to avoid rating bias as mentioned above. So despite of having proven its worth, there is a need for empirical tools specifically matching the competence model and the learning arrangement in order to rate the students equally. The aim of this study is to develop empirically based interventions, so that the student tutors and scientific supervisors are able to validly assess the learning development process. For the successful evaluation of soft skills, there are several requirements: The tutors and supervisors need to know, understand and accept the educational objectives of the soft skills. They also need to master the didactical interventions and should have certainty in dealing with the indicators of the competencies, with which they provide feedback to the supervised student teams and initiate competence development.

As mentioned above, the competence development is monitored and with evaluation criteria and a corresponding form sheet. On this form, each of the five dimensions of the competence model is assessed. We will however focus on the final three aforementioned "soft" skills, which are difficult to assess practically [9]. Therefore, there is a need to develop an empirically based didactical interventions in order to have a reliable assessment tool.

4 RESEARCH METHOD – THE INTERVENTION TOOLBOX

The first step to develop such an assessment tool would be to investigate how the practice of assessment has taken place up until now. Thirty-nine observational sessions took place and were carried out by various student teams. They observed the specific workshop situations and the private working meetings of the students. An additional six scientific supervisors were interviewed during this process. Through this practical view on product design education at tertiary, a competence development guideline was created (table 1). This includes systematic indicators, with which the tutors and the scientific supervisors are able to assess the students. This guideline is specifically used for the teaching practices at the Institute of Product Development. The guide is short, no longer than one page, but still needs to address every dimension for each of the competencies. In further work, the individual dimensions will be literary founded to a greater extent and elaborated in more detail. For every partial-dimension, there will be one to three short interventions developed for the practical project work.

For the interdisciplinary competence dimensions, observable examples need to be found. This means, the tutor rates the performance of the students and not their competence. For team work, this area should be broken down individually. The observed skill groups are based on literature written by Geis [10]. This area has been analyzed in his writings "Behavioural Markers in Product Development Success and Power Factors in Team Effectivity". He names the following aspects as part of successful teamwork:

- Communicative strategies such as feedback and active listening
- Strategies for conflict management
- Situation analysis and assessment
- Process planning and execution
- Reflection

Supplementary to these aspects named by Geis, the point "capture multiple perspectives" should also be added. This means that knowledge should be flexibly transferred to other problematic situations. This can be seen as one of the most important skills an engineer may possess. The corresponding interventions are required to be short time-wise, so that they can easily be integrated into the four-hour block event. Furthermore, the interventions should not require a long familiarization phase; the tutor and the scientific supervisor should be able to apply the methods immediately. The following will introduce examples of the most plausible interventions for team work (table 2). For a better understanding, a few interventions methods are detailed below.

Table 2. Skill Sets and possible Interventions

Skill Set [10]	**Possible Intervention [11, 12, 13]**
Communicative strategies (Feedback and active listening)	Organized Feedback, SIL
Strategies for conflict management	Advocate Method, Muddiest Point, Pro-Contra Argumentation
Situation analysis and assessment	Metaplan technique, Active structuration
Process planning and execution (milestones)	Project planning, Project oriented learning
Reflection	Questioning technique, Flashlight
Multiple perspectives (flexibly transfer knowledge to other problematic situations)	Headstand method, Six Thinking Hats [14]

Interexchange and active listening can be stimulated via the SIL (translated as Systematic Integration of Solution Elements). For this process, each team member compiles their own approach to solving a problem individually. Their suggestions are in turn presented and a high quality combined solution is built by the team as a whole using the benefits found within the individual ideas. The Advocate Method prepares students for possible conflicts later in their everyday working life and also helps to assert their own ideas through direct opposition. The Tutor or one of the group members takes the position of the "advocate". He gives arguments in which the group does not agree with. So the others are engaged in an argumentative discussion process. With Muddiest Point, every group member is required to name the task aspects which appeared to be the most difficult or confusing. In a Muddiest Point exercise, students are asked to report what idea, topic, etc. about the previous workshop was confusing or unclear. The tutors and scientific supervisors collect all "Muddiest Point" responses and later read and analyze them to see what areas of the lesson or assignments students are unclear about. Students learn to articulate difficult topics and the faculty members get a direct feedback for their work. The headstand method is based on the reversal of the original problem. The students leave their customary thought patterns, and are then in the position to methodically transfer their knowledge to other problematic situations.

5 CONCLUSION AND OUTLOOK

In retrospect, evaluating the learning outcomes of soft skills in mechanical engineering education can be achieved with the right amount of structure, guidance and direction. In regard to teamwork, a literary analysis supplement should be created for the partial skills highlighting the respective measures required to evaluate creativity and strength of implementation. Interventions should be made available to the tutors and the scientific supervisors in a structured and manageable form as an intervention toolbox. This toolbox contains guiding information about in which phase of the project work the interventions should be applied. For example, at the beginning of the brainstorming session or rather at the end before the final presentation. Furthermore, there is a precise schedule with guiding tips which directs the observation of the competence dimensions. Through all of these steps, the tutors not only ensure that the competencies are more visible, therefore being easier to rate, but are also able to specifically target the development of these skills.

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