FROM LEARNING TO EXPERIENCING PRINCIPLES OF ENGINEERING DESIGN AT THE TUM

Ioanna MICHAILIDOU, Michael ROTH and Udo LINDEMANN
Institute of Product Development, Technische Universität München

ABSTRACT
The lecture "Principles of engineering design and production systems" is a lecture attended by Bachelor students in their second semester of studies in mechanical engineering at the Technische Universität München. Since April 2013, the lecture has been extended by a student project, in which the approx. 800 participants, divided in groups of 15, were asked to carry out a development process and conceptualize an innovative product by applying the contents taught in the lecture. The goal was to increase the learning effect of the course through the benefits of experiential learning and project work. The participants are expected to develop technical and social skills, which are important for their future career as engineers. The motivation for restructuring the course, the contents of lecture and project, observations and feedback collected after the first project completion, as well as improvement suggestions are presented in this paper.

Keywords: Engineering education, student project, design methods

1 INTRODUCTION

For the past 50 years, engineering education has been science-based, stressing analytical, problem solving skills rather than the broader skills of engineering design, systems integration and innovation. A deep technical education in the engineering field chosen is, of course, essential. But a large set of additional skills, ranging from creativity and innovation to life-long learning are equally important for modern engineers. At the Technische Universität München, the lecture "Principles of engineering design and production systems" is a lecture attended by Bachelor students in their second semester of studies in mechanical engineering. In the lecture, theoretical foundations for development of technical products are being taught. Since April 2013, the lecture has been extended by a student project, in which the approx. 800 participants, divided in groups of 15, were asked to carry out an exemplary development process and conceptualize an innovative product by applying the contents taught in the lecture. Through the new project-oriented structure students are supposed to gain a better understanding of the theory presented in the lecture and increase their technical and social competences.

Goals and advantages of experiential learning and project work in engineering education, as well as the motivation for restructuring the course are presented in section 2. The contents of lecture and project are described in section 3, while lessons learnt based on observations and feedback collected after the first project completion are presented in section 4.

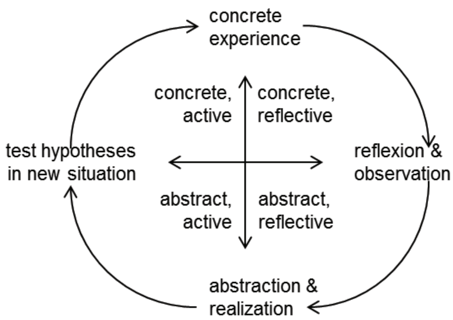
2 BACKGROUND, MOTIVATION AND GOALS

2.1 Experiential learning and project work in engineering education

The learning outcomes of engineering education should be useful for universities but also for the society. Using academic learning for increasing employability and citizenship requires multidisciplinary, subject-related competencies [1]. The importance of those competences in the field of engineering is emphasized by VDI [2]. They claim that, beside the 30% fundamentals of mathematics and natural sciences and 30% for fundamentals of engineering, the structure of engineering studies should involve 20% application-oriented basic knowledge and engineering-based problem-solving methodology and 20% multidisciplinary skills. A study of VDMA in 2004 [3] reflects the some idea concerning mechanical engineering in practice: 80% of the enterprises asked wished for more interdisciplinary knowledge as well as social and methodical competences from their employees. 70% confirmed that education should be more praxis-oriented, while 60% had no wish for the theoretical knowledge to be extended. A practitioners' profile analysis conducted by Brandstetter [4] shows that social, personal and methodical competences play a vital role for German engineering enterprises. There are a number of modern teaching methods which aim at increasing those competences, including the approaches of: experiential learning, open classes, free labour, project learning, hands-on learning, action-oriented teaching, and Freinet Education [5]. In following sections, the approaches of experiential learning and project work are analysed, as most relevant for the agenda of the Technische Universität München and for the course selected.

2.1.1 Experiential learning

Experiential learning is the process of production of meaning through direct experience. The theory of experiential learning bases on the work of Dewey -from the field of philosophy, Lewin –with focus on team dynamics, and Piaget -learning as interaction process, but has been founded by D. A. Kolb [6]. The term "experiential learning" describes learning which results from direct participation in the events of life. It refers to a holistic approach to learning, combining experience, perception, cognition and behaviour. According to the experiential approach, learning is the process in which knowledge is created through the transformation of experience. It requires direct contact with the phenomenon being studied, rather than simply studying or reflecting it. Experiential learning involves analysis and initiative and, opposed to academic learning, is not reproductive. No teacher is required and learning relates only to the process of directly experiencing. The learning process is individual and requires therefore some conditions, such as the student being willing to engage actively, being able to reflect upon their experiences, having the capacity to understand the experience and decision making skills to use the new knowledge.



Experiential learning
…builds on the experiences of students or causes new experiences.
…encourages students to participate actively in the learning process and to invest personal interest in it.
…urges to explore and discover, while it activates imagination and creativity, promoting students´ self-awareness.
…urges to find or create meaning instead of memorizing information.
…considers an integrated mental and emotional process, since learning is based on the relationship and interaction of knowledge and emotional processes.

Figure 1. Kolb's experiential learning circle [6] and principles of experiential learning [7]

2.1.2 Project work

In project work it comes to an acting-teaching process on a concrete task. Within the framework of a project, emphasis is put upon practical realization by the participants and self-planning and self-responsibility are required. According to the definition of a project in DIN 69901, a project takes place in unique conditions, has a specific target goal (concerning time, financial and personal aspects), and is realized by a unique plan in a project-specific organization. Other dimensions of projects beside uniqueness are: complexity, interdisciplinarity, team-work and significance [8]. The learning objective of project work is to increase the participants' competences in: methodological proceeding towards a solution, autonomous work, documentation and further use of the results, working economics, critique skills, subject-specific knowledge, collaboration and communication. Thus project work forms the basis for collaborative and research-based learning in studies [9]. According to [4], project work and learning through research are the most effective teaching and learning methods in engineering education, when organizations and their members go new ways in the context of key competences. These course forms represent an effective combination of technical, methodological and social skills, when: The basis of the project is constituted by a research question, a project- or problem-solving task with technical content; Students are provided knowledge of methods such as project and time management, creativity techniques and models on teamwork and communication within preparation workshops; Team meetings are process-oriented and closely and continuously supervised and reflected by and with teachers.

Those characteristics of project work and requirements for its effective application have been taken into consideration for creating a new teaching concept for the lecture "Principles of engineering design and production systems".

2.2 Motivation for restructuring the lecture

The motivation for restructuring the lecture "Principles of engineering design and production systems" was to increase the learning effect and support students in the transfer process of academic knowledge into engineering design application. The combination of theory and application should reinforce a sustainable learning effect and higher sensitizing to engineering technology from the students´ side.

The yearly course evaluation in the last years has shown that the course was considered rather "too theoretical" and "dry" by the students. Those comments are representative examples of the students´ opinion of the lecture and highlight the need for a reconstructing it. On the other hand, the "TUTOR system Garching" [10], a volunteer program based on student initiative, has been a positive example of students' engagement in team work and innovative product development. The TUTOR system gives students a methodical and social qualification within workshops on topics, such as: group development and work in a team, communication, facilitation, presentation, learning techniques, time and self-management, working with targets.

The new concept for teaching the principles of engineering design is based on those two components: the course, providing fundamental technical knowledge and the team work, providing a praxis-oriented application of this knowledge. The new teaching concept has been developed by Professor Dr.-Ing. U. Lindemann and scientific assistants, who supervised the course, within workshops and discussions. The main objective of the new teaching concept is to enable students to understand the qualifications required in the development and production activities, and their context in the overall product development process. A development process from goal definition to concept execution is simulated within teams of 12-15 students. Thus, challenges of real developments projects become clear and students learn how to confront them. A further goal is, that students apply the lecture contents in their own projects. Development models, methods, as well as principles of engineering design should be applied by the students. Thus they are able to develop, analyse and evaluate solutions for development tasks. A design brief is given in the beginning of the semester, providing the student teams with an example for applying these contents. Dealing with a concrete product should motivate the students and enhance their engagement.

3 STRUCTURE OF THE LECTURE

The module consists of the course "Principles of Engineering Design and Production Systems" (i.e. lecture) and the processing of a development task in a student team (i.e. project). While the exam on the lecture's theory is held as a written exam, the project results are assessed during an oral presentation about the group's proceeding and the product developed.

3.1 Lecture

In the lecture, theoretical foundations for development of technical products are being taught. The lecture is offered by the Institute of Product development, being responsible for teaching the fundamentals of product development and organising the lecture, supported by three further institutes for production and manufacturing. Until 2012, content concerning product development and production systems was presented in the lecture in sequence. In 2013, the two theoretical parts of the lecture were offered in parallel, with the part concerning production beginning in the second half of the semester in five lectures on *Fundamentals of production technology and manufacturing*. Figure 2 depicts the theoretical contents of the lecture. The fields in *italics* represent the contents on production systems, which in 2013 have been offered separately.

The product development process is presented with focus on supporting the individual process steps. The Munich Procedural Model [11] is introduced as guideline for developing a product. Methods for abstract description and analysis of complex technical products are presented. In addition to the basic manufacturing processes, rules and principles for materials selection and structural design of technical products are introduced. Finally, construction procedures and the systematic influence on production costs are presented. The theoretical part of the course on product development consists of 12 weekly lectures of 90 minutes. The contents of the lecture are presented as PowerPoint slides, while real objects used as examples are shown during the lecture. The slides extended by explanatory text are published as teaching material.

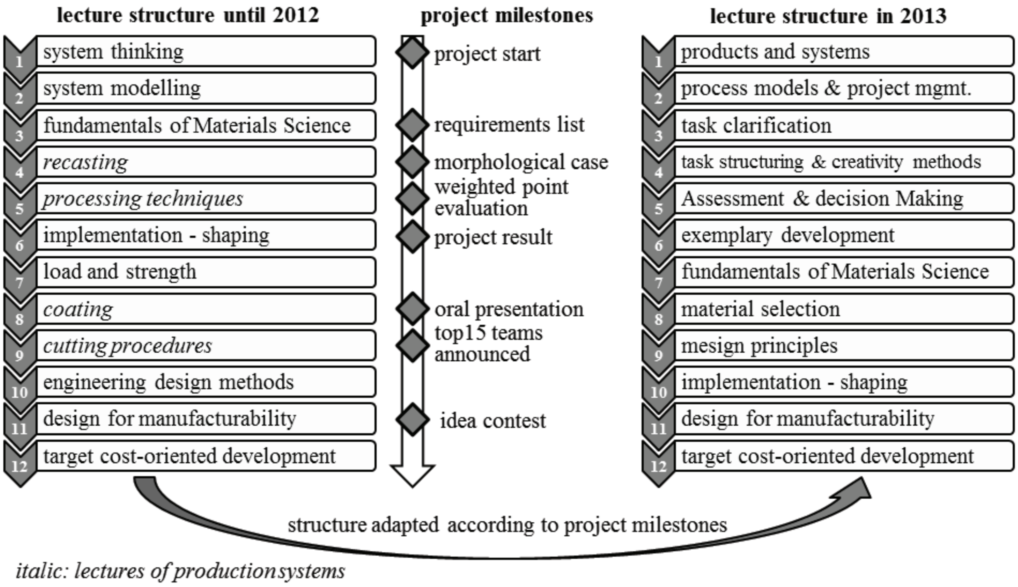


Figure 2. Contents of the lecture “Principles of engineering design and production systems”

3.1.1 Written exam

In the written exam, the knowledge of the taught content is assessed. Thus, the focus lies on the detailed knowledge of methods, manufacturing processes as well as the principles of materials selection and design methodology. The exam lasts 90-minutes and contains about 90 multiple-choice (type: single-choice) questions. As result the students are regularly graded and the received grade determines the grade for the whole module. In case the project part is passed, students who succeeded in the written exam receive 4 ECTS.

3.2 Project

In the project 10-15 students work for 7 weeks on a development task in teams applying the theoretical content in practice. The teams had worked together in the “TUTOR program” provided in the former (first) semester and thus obtain knowledge in soft skills (workshop topics are presented in 2.2). The results of the development project are assessed within an oral presentation, in which each student group presents their results on a DIN A0 poster. As the intended learning outcomes are the exemplary application of taught methods and the experiencing of a product development task, the main focus of the assessment lies on the application and learning effects instead of the achieved product quality. In the beginning of the semester, students are provided with a design brief, a template for the poster (Figure 2). On the poster, the methodological approach should be presented with the stated methods and their results to each of the following development phases: Task clarification (requirements list), solution search (morphological case and creativity method 6-3-5) and concept selection (weighted point evaluation). Particular attention is paid to: completeness, compliance with formal rules, proper application of methods, reflection of the methods application, useful application and reflection of the procedure (e.g. challenges, iterations), and overall impression.

3.2.1 Oral exam

In a 10-minute presentation the groups each have to present their developed idea and concept, integrate their proceeding into the Munich Procedure Model, present the application of four selected methods in detail and reflect and discuss their overall proceeding. The presentation is held orally, based on a poster according to the template in Figure 3. The students may split the presenter’s role or choose a single presenter. Subsequently the group is interrogated and their knowledge and understanding of the methods is assessed by an oral questioning. Here the examiners are instructed to explicitly interrogate all group members. The main criteria of the assessment are the correct and expedient application of the methods and the understanding of these methods. Moreover the proceeding and reflection as well as the presentation are considered. All members of the group finally are graded “passed” or “not passed”. In the first project run in 2013 a jury simultaneously rated the creativity of the product idea, which built the base for a voluntary idea contest among the 15 top teams.

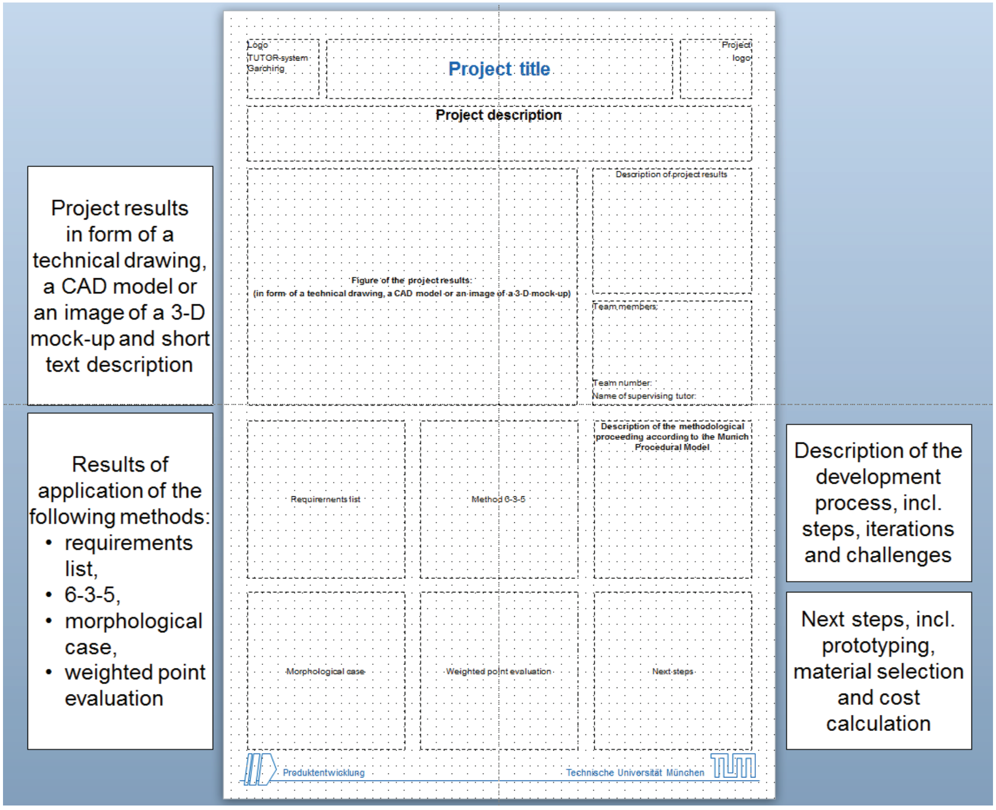


Figure 3. Poster template for presentation of the project

4 OBSERVATIONS AND FEEDBACK

During the first run of the course in 2013, revealing observations were made and feedback of participants, tutors and supervisors was collected, concerning 3 main issues:

4.1 Level of detail in task specification

The brief given to the project participant was the theme: “Back to nature: survival of the best equipped”. The topic has been defined by tutors organizing the idea contest and scientific assistants. The motivation for selecting a theme rather than a specific product was to enable the students to confront the challenges of task definition and task specification [11]. According to the participants this challenge was way too demanding and it took some groups up to 3 weeks to find the final product idea. Reflecting on this topic, the scientific assistants agreed that the time span of 7 weeks does not allow such an extensive task clarification and in future more specifications, like target group and product category will be predefined. The methods to be applied by the group will also be predefined in 2014, since many groups had difficulties in choosing the appropriate method.

4.2 Focus on the engineering process instead of product

After the oral presentations and the publication of the results many students were disappointed regarding the evaluation of their ideas. Obviously the students tend to focus on their product idea itself, while method application and expected learning outcomes move out of scope. Participants wanted to present their developed ideas instead of the methodological application. This explains their reaction, when they mainly are questioned on the methods and principles they applied. Yet, this notion shows, that one main aspect, the importance of methodology, is not completely understood by the students. In order to avoid an inhibition of the students’ creativity it is essential to reduce these negative impressions. Our approach for 2014 is to explicitly communicate the separation between product idea and application of the methods. Therefore the assessment of the product idea and creativity will be shifted to a separate event prior to the oral exam. Thus, we expect the students to realize the focus of the oral presentation and to reduce possible disappointment.

4.3 Organizational aspects

Many participants expressed the wish to get a clearer description of the expected results from the beginning of the project. The example shown in the sixth week helped, but came rather late. To improve this aspect, in 2014 the exemplary development will be shown in the second week and will be enriched with results from the projects in 2013. In every lecture, slides with examples and references to the project work will be added. In 2013 the supervision with regard to methodological application was on demand. Evaluation has shown that this was insufficient, since many teams applied methods incorrectly. Additionally weekly office hours will be provided during the whole duration of the project to provide better support to the young developers. Project duration has also been an issue for the students; therefore the project timeline will be extended by 2 weeks in 2014.

5 CONCLUSIONS

Applying the principles of project work, experiential learning and good practice in education [12], the course "Principles of Engineering Design and Production Systems" has been reconstructed. The learning effect and the sustainability of the lecture are increased due to practical application within an engineering project. Through the project work positive influence on future projects or the Bachelor Thesis is expected. Following participants', tutors' and supervisors' feedback, further improvements will be made: changes in lecture structure (order of courses), more specifications and clearer focus on methods, extension of project duration and weekly office hours. To reward assiduous project work the written exam will be extended by more transfer questions.

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