Innovative Teaching & Learning Projects in Engineering Education:
Didactic Approaches for first-year Students

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INTRODUCTION

TU Berlin is facing particular challenges in its engineering education due to its size: more than 30 000 students in 100 degree programmes and about 300 full-time professors assigned to 7 faculties need to assure that quality teaching and large student numbers are not an inextricable contradiction [1]. A fundamental task – and also one of the most pressing questions – is (how) to improve the attractiveness of engineering curricula in general and the retention rate of students during their first year of studies in particular. Therefore, this contribution focuses on a detailed survey of 2 innovative teaching projects which are the fundamentals of engineering education at *any* university: the lectures[1] about “Mathematics for Engineers: Analysis I” and “Foundations of Electrical Engineering” (GLET). It will illustrate the concept of these 2 modules, their implementation and their evaluation design.

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[1] In the German system, lectures are usually accompanied by an exercise class and tutorials. In most cases, lectures are delivered by professors. Exercise classes that serve to deepen the understanding of the material and to answer questions in larger groups are led by (research and) teaching assistants. Tutorials as an additional opportunity to practice e.g. mathematics in smaller groups are executed by student tutors.

1 GENERAL CONSIDERATIONS

1.1 Status Quo

Teaching large classes of first year-students in the STEM-courses, which are perceived to be difficult, complex and exclusively focused on basic theory, is not an easy task. This is also true for TU Berlin. Due to its size, quality teaching during lectures with high student numbers needs to be ensured. However, first year-students are also facing challenges when they are confronted with lectures during their freshmen year that involve up to 1000 students – sometimes even more – and are often crucial for their study success. In order to address the problems of considerably high drop out-rates during the first year and of decreasing attractiveness of engineering curricula in succession, our corresponding study reform concentrates on interactive teaching and learning methods, especially in the highly frequented lectures of the basic STEM-courses.

1.2 The study reform project

The overall goal of this reform project, which is funded by the German Federal Ministry of Education and Research, is the creation of an interactive teaching and learning environment which supports learning, is participatory and helps to establish a new teaching and learning culture. This means the realisation of a better student-to-teacher-ratio, quality enhancement in teaching by using improved didactic methods and the development of innovative teaching curricula. TU Berlin wants to offer premium-quality studies and to educate students in a way that good teaching practice is established as standard, which they will subsequently call for during their whole study period. In order to reach this goal, *quantitative* measures, such as the purposeful temporary increase of teaching staff[2], need to be accompanied by *qualitative* measures, e.g. in the fields of continuing education and qualification, counselling and assistance for teaching staff and specific offers to support studying and learning of students. The success of the study reform at TU Berlin is promoted by putting it on the firm footing of rather diverse projects in order to tackle all relevant causes that might contribute to study failure. ***tu wimi plus*** is one among 8 projects at TU Berlin to provide better study conditions and to improve the quality of teaching and learning. For this project, additional teaching assistants have been employed in selected, challenging areas of our university to provide didactically qualified staff. Besides the improvement of their teaching competences and their long-term work as disseminators of good teaching practices within their own institutes[3], their key task is to develop innovative teaching curricula within the frame of teaching projects, which they apply directly in their own subject-specific teaching [2].

1.3 Innovative Teaching Projects

Currently, ***tu wimi plus*** provides support for the conception and implementation of 8 innovative teaching projects, which are located at thematically very different chairs and vary greatly in nature: 4 projects are hosted by the chairs in “aircraft and light-weight construction”, “continuum mechanics and material theory” (2 projects) and “construction informatics”. They have extended and reworked their course offers by adapting the material to the latest didactic standards, also fostering digital learning. 2 projects are executed by the chairs in “micro-technology” and in “thermodynamics and thermal process engineering”. Whereas the first has developed a completely

[2] Teaching staff comprises professors, (post) doctoral teaching assistants and student tutors.
[3] Cf. conference submission of Rummler, M., Nikol, P., Training of Change Agents for Engineering Education: A Concept for Improving Teaching and Learning of Students.

new study module focusing on e-mobility, the latter is in the process of establishing a process technology laboratory. Another 2 projects are "Mathematics for Engineers: Analysis I", initiated by the "Service Institute of Mathematics", located at the chair in "modelling, simulation and optimization in natural and engineering sciences", and GLET, carried out by the chair in "light engineering"[4]. As referring to all projects would be clearly beyond the scope of this paper, we concentrate on "Mathematics for Engineers: Analysis I" and GLET[5] as they have to be attended during the first study year and passing or failing these exams is crucial for future study success.

2 INNOVATIVE TEACHING AND LEARNING

2.1 Elements of Innovative Teaching and Learning

Recently, the concept of innovative teaching and learning practice has been mentioned quite often. Although a consistent definition of the term does not exist, an internet search for the offers of different German universities across all subjects revealed that "innovative studies" seem to be focused on some basic points. Examples are: to combine different forms of traditional learning methods with formats that use new digital media to foster learning, to allow for individually designed curricula or long distance studies, to link practical and theoretical education, e.g. by transferring newly acquired knowledge directly into practical applications, or to develop the necessary skills to create awareness for problems, analyse and solve them – all based on teaching-learning-processes. This list does not claim to be complete. Innovative teaching must encompass a combination of different characteristics and requires specialist knowledge from teaching staff in terms of didactical methods and the appropriate use of digital media. Teaching has experienced a shift – also in the role that teaching staff have to fulfill – from lecturers to counsellors and creators of excellent learning processes. Thus, innovative learning comprises e.g. digital media skills, learning efficiency, the ability to work in teams, entrepreneurial thinking, multilingualism and interest in new technologies [3]. The question, which strategies foster innovation in this context, can be answered by considering the main innovative learning principles: *learning approach*: problem- and project-based learning, context-oriented; *contents approach*: interdisciplinary, exemplary learning; s*ocial approach:* team-oriented, participant-directed learning [4].

2.2 Challenges for first-year Students

To apply innovative learning strategies, is quite a difficult task for first-year students. *First,* they need to cope with general challenges, such as getting familiar with the surroundings or participating in lectures in large classes, which represents a learning format that they have not known before. Hence, they need to learn *how to* learn at university level. *Second*, there are also technical challenges that they have to face. As the requirements at grammar schools are quite diverse in Germany, the first-year students´ knowledge is very heterogeneous – especially in mathematics, which is one of the key subjects to succeed in studying engineering. From the students´ point of view, the judgement of their knowledge level right at the beginning of their studies may lead to various false estimations in terms of their study behavior: On the one hand, poor learners need to recognize very quickly that their previous knowledge might be insufficient. They must be aware that it is their individual responsibility to search for support offers to be able to keep up pace. On the other hand, also good learners can fail. If school knowledge is repeated over and over again during the first

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[4]For an overview of the teaching projects see http://www.zewk.tu-berlin.de/?id=123826 (15-05-2013).
[5] "Mathematics for Engineers: Analysis I" and GLET offer no exercise classes; therefore the tutorials – besides the lecture – play an important role in the active teaching and learning process.

lectures to provide other students with the necessary basic knowledge, they might feel tempted not to attend them anymore and stay away. However, when they decide to come back a few weeks later, they have probably missed the connection as they are not aware that the content will be dealt with faster than at school.

2.3 Interactive Teaching Methods

In order to bridge this gap between the technical requirements of TU Berlin in the basic STEM-courses and the general and technical difficulties first-year students are facing, innovative approaches including interactive teaching and learning methods are used more frequently. Due to the shift from teaching to learning, teaching staff are assigned to enable activity in all phases of the learning process and to create a pleasant learning environment that fulfills the students´ needs. Good teaching practice – and this is particularly true for large classes! – requires practical examples, needs to be professionally oriented and to integrate persons, themes and methods; it uses real life examples, which are geared to the living environment of the students, and creates the possibility to develop competences.

In order to implement student-centred approaches, a variety of learning methods can be considered. However, we focus on the most relevant ones within the scope of "Mathematics for Engineers: Analysis I" and "Foundations of Electrical Engineering": *Problem-based learning* uses complex, real world situations as an incentive and a challenge to start the learning process. Students work in teams to discuss the problem, identify learning gaps and offer viable solutions whereas the teaching staff act as pure facilitators and not as lecturers [4]. *Digital learning* means to foster the learning process by providing the students with technical means, such as moodle-platforms for discussions, online-exercises and calculations, videos, podcasts and the like, to create a rich learning environment and to deepen their knowledge in the subject. *Activating teaching* describes a good teaching practice which is based on the fact that the attention span of students naturally decreases after a period of 20 to 30 minutes if solely listening to teaching staff without being actively involved. Didactic tools, such as open questions, group work, discussions, role plays, world cafés and the like, help to raise the activity level of the students, make them think about the content and foster learning success.

3 TEACHING PROJECT 1: MATHEMATICS FOR ENGINEERS: ANALYSIS I

3.1 Status Quo

The *first* teaching project, "Analysis I" is a mandatory study course (8 ECTS) for *all* engineering students at TU Berlin during their first year of studies. Like the other 2 basic courses in mathematics, "Analysis II" and "Linear Algebra", it is hosted by the "Service Institute of Mathematics", which is also held responsible for the organization of the whole course offer, including early-bird and repetition courses to bridge the knowledge gap between school and university level. The exact number of participants is not easy to determine as the students pursue quite distinct intentions. Therefore, registering for the exam can be done in order to repeat the exam, to get access to the exercise material or simply to estimate the level of complexity of the lecture. Accordingly, the demands on teaching and learning are as heterogeneous as the students´ motivations, which makes it difficult for teaching staff to meet all the requirements. On average, "Analysis I" needs to be successfully completed by 1500 students each semester, sometimes even more.[6] Lectures are offered every term, which requires 3 to 5 professors for lectures, 2 teaching assistants and about 15 to

[6] Number of students during the winter term 2012/2013: 2100 [5]

20 student tutors[7] for tutorials. 50 parallel tutorials are offered during the summer term, 65 during the winter term.

The major challenge lies in the improvement of the relatively high failure rate of the written final exams in “Analysis I”, which varies considerably from semester to semester. Generally, the exam has to be repeated by every second or third student. To get accepted for the exam, students need to reach between 50% and 60% of all possible points in their homework exercises. Each worksheet comprises of four mathematical problems that can be solved in groups of 3 students and need to be handed in on a weekly basis. Like this, the students keep practicing from the start and group work encourages them to discuss possible solutions. Overall, about 60% of the beginners manage to overcome this barrier, which means that the majority of all engineering student drop outs has never participated in any mathematics exam. This is especially relevant because the curriculum of first-year engineering students mainly consists of subjects which cannot be understood and dealt with without a sound knowledge of mathematics, such as mechanics, physics, physical chemistry, thermodynamics or electrical engineering. However, due to the possibilities of taking any written exam twice and getting an oral examination if a third attempt is necessary only 2 among 1000 students who participate in the exam will subsequently fail completely [5].

3.2 Concept

As we have already mentioned, the overall *objective* of the didactic development of “Analysis I” for engineers is the facilitation of the transition from school to university by supporting the students to acquire learning competences and self-learning strategies. Even though this paper focuses on the improvement of the quality of teaching and learning by innovative methods (see 3.3), there are 2 more aspects which need to be considered to provide the frame for a productive learning environment, which will be outlined briefly: the quality of organisation and the quality and quantity of the content of the offer. The *quality of organisation* is ensured by various measures: *First*, every lecture of “Analysis I” is paralleled three to five times (depending on the number of students), which reduces the number of participants per lecture to a maximum of 500. *Second*, exams are offered four times a year (before and after the winter and summer term), the assessment is tied to a fixed grading key and past exams are available for exercising. *Third*, an authorised script, the syllabus and weekly coordination of the lecture´s content between all teaching staff involved allow concerted timing. The *quality and quantity of the content* determine an engineer´s qualification. At TU Berlin, the expected material is internationally comparable and draws on a script, which has been developed by experienced researchers who are able to judge the importance and relevance of the particular content for engineering education and practice. Hence, the consistency in quality and quantity of the content ensures an equal level of complexity and quality of all parallel lectures respectively [5]. The creation of an equal standard, that has been working quite well for lectures so far, is now ought to be transferred to tutorials and the worksheets successfully.

3.3 Implementation

Considering the given scenario, the most important question is: How can innovative teaching and learning methods be integrated in the course offer to foster students´ activity and initiative? As we have mentioned earlier on, one of the key success

[7] Generally, student tutors are higher level students with a sound knowledge of their subject.

strategies for students to pass the exam is to be motivated to practice (mathematical) problem solving over and over again. Moreover, problem solving is a key competence in the engineer´s working life, which requires e.g. creativity, experience and the capability of working in heterogeneous teams. Therefore, innovative teaching and learning methods that are most suitable to foster the development of the necessary skills are *problem-based* and *digital learning,* also using *activating teaching methods*. Although it is true that every mathematical exercise contains a particular problem and that problem solving is, hence, an integral part of all lectures, teaching staff have not implemented the problem-based approach as it is understood by de Graff and Kolmos [5] yet. However, all teaching is done from a *problem-oriented* point of view and shall gradually be developed towards problem-based learning.

However, it is the tutorials, accommodating relatively small groups of 20 to 30 students, that play a major role in fostering group work and in activating participants. During the tutorials, teaching staff[8] encourage students to find solutions in small groups and give supportive feedback. In addition, the worksheets, which are done for homework in groups of 3 persons, corrected and given back at the beginning of the tutorials, represent a very valuable source for feedback and facilitate the learning progress. Moreover, all teaching materials for tutorials and home exercises – for students *and* for student tutors – have been didactically adapted during the winter term 2012/2013 by the teaching staff provided by ***tu wimi plus*** to promote learning success and set clear quality standard for all tutorials. Since then, the teaching assistants have also been working on the consolidation of quite extensive teaching materials, enriched by visualisations and interactive exercises. The future aim is to broaden the offer of blended-learning formats and interactive exercises. *Digital learning* in the context of “Analysis I” particularly means the advancement of MUMIE[9], which is an interactive learning platform and has already been integrated in the homework exercises. This means, that teaching staff both have to select appropriate electronic exercises from the existing pool and create and programme new exercises in areas that have not been covered before. From the teaching staff´s perspective, the effects of the MUMIE have been quite promising so far: Simple and routine content and techniques can be learned and applied quite well, it creates excellent possibilities for demonstrations and visualisations and extra material to deepen understanding can be stored and retrieved by students. In addition – and most important – the auto correction function for the homework exercises has resulted in some workload relief for teaching staff which contributes to the provision of extra time for individual student support face to face. However, it cannot be denied that this is pioneering work and that there is still a very high demand for the creation of interactive exercises (no multiple choice).

4 TEACHING PROJECT 2: FOUNDATIONS OF ELECTRICAL ENGINEERING

4.1 Status Quo

The *second* teaching project, GLET, is an obligatory study module (7 ECTS) for all students of electrical or industrial engineering and technical computer sciences at TU Berlin. It is hosted by the chair in “light engineering”. On average, the lecture is frequented by 800 first-year students and only offered during winter terms. Required human resources are one professor (chair leader) for lectures, 3 teaching assistants

[8] Tutorials are mainly executed by student tutors, but also by teaching assistants. Both have the possibility to get free training in didactics to improve the quality of teaching and learning.
[9] MUMIE stands for multimedia-based education in mathematics.

and 15 student tutors for 30 tutorials.[10] On average, electrical engineering has to deal with an overall failure rate of 2/3, considering the number of students who actively participate in the final module exam. Though, the number of beginners who registers for and attends the exam in fact varies from semester to semester. Sometimes, just every second student uses the first possibility to participate in the exam although there is no formal barrier. To get accepted for the exam, students need do prepare 4 worksheets individually and hand them in; three of them (the best ones) are selected and make up 1/3 of the final grade. However, there is no minimum number of points that needs to be reached; passing the exam is all-dominant. On the one hand, it becomes quite clear that the situation is worsened – or even caused! – by the fact that students are often missing the basic knowledge in mathematics (see teaching project 1), which is indispensable to be able to understand the content of the lecture in electrical engineering. On the other hand, first-year students often have great difficulty in learning abstract theory which seems to bear little reference to daily life. Here, innovative teaching needs to step in.

4.2 Concept

Taking into account the given facts, the most pressing questions are: How can the course didactically be modified? What kind of innovative methods can be integrated to raise the students´ enthusiasm about the topic, to increase the attractiveness of the module and to reduce the failure rate subsequently? To address these challenges, the professor fancied the idea of transferring natural electrical phenomena, such as lightning, to the study context. Similar to the principles of a construction kit, a multi-level analysis is provided: Every phenomenon is named, explained and illustrated by the conduction of an appropriate experiment. This procedure is determined to close the gap between theory and practice and creates a learning environment for students which is *problem-based* (or better problem-oriented, but being developed towards a problem-based approach), *digital* (e.g. by the use of 3D-animations or exercises using MUMIE) and fosters *activating teaching* (e.g. by asking the students to build a condenser from household materials, explaining the principles of how and why it works).

The *lectures* are one of the key success factors in electrical engineering. During the winter term 2012/2013, the teaching staff have started to reshape the lecture itself by integrating realistic examples, movie clips, live-experiments and 3D-animations. Moreover, ad hoc exercises for calculations have been included in the script that need to be done during the lecture (individually or in small groups) to foster the students´ activity. Besides the lectures, the second important pillar to support activity-based learning is formed by the tutorials, which comprise rather small groups of up to 30 students. For the newly designed practical exercises and calculations, the whole group is divided into groups of a maximum of 6 persons to achieve good learning results. Exercises for the tutorial are provided and can be prepared in advance which supports group discussion and problem-solving competencies during the tutorial. To ensure a high quality and equal standard in all student tutorials, a lot of emphasis is put on improving the didactic skills of the student teaching staff. During the last winter term, weekly workshops on different topics were carried out by the teaching assistants and one-to-one coachings were offered to student tutors as requested. Furthermore, the professor has initialized a weekly meeting to collect ideas how even more innovative elements could be integrated in the existing course programme. One

[10] In addition, 2 tutorials for foreign exchange students are offered.

of these brainstormings led to the idea to use twitter, facebook and rss newsfeed to spread community news and it is in its trial period right now.

During the term of ***tu wimi plus***, there are several measures planned to improve the course offer continually: expansion of the topics which are explicable by experiments, subsequent adaption of the worksheets, integration of simulation tools into the lecture and finally the creation of a completely new script. Another idea is to provide recordings of the lecture, e.g. with an open source software like “Matterhorn”[11].

5 EVALUATION

The evaluation of lectures is getting more and more important in the university context due to quality aspects. This is also true in the context of ***tu wimi plus***. It is discussed to develop a draft of a questionnaire which matches the learning objectives of the lecture and combines elements of the Unizensus-questionnaire (which is traditionally used at TU Berlin)[12] with elements of the NSSE-questionnaire[13]. The latter emphasises the activities that the students are ought to perform rather than concentrating on their contentment with lectures, seminars or tutorials. A pilot study in our teaching projects with a newly designed questionnaire could be an inspiration for full evaluation in the next project period.

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[12] http://www.tu-berlin.de/evaluation/evaluation_von_lehrveranstaltungen/menue/das_owl_projekt_elv/
[13] Further information about NSSE can be found here: http://nsse.iub.edu/ (15-05-2013)