Lecture Meets Laboratory

Experimental Experiences for Large Audiences: Concept and Implementation

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***Abstract*—Lecture courses are an integral part of academia with a long tradition. The efficiency of such courses can be notably increased by active participation of students in the learning process. This article will elaborate on a re-structuring of an engineering lecture attended by more than 400 students; during the course, laboratory experiments are integrated directly into the lecture, allowing students to gain their own practical experience.**

***Index Terms*—laboratory skills, hands-on experience, active learning**

I. INTRODUCTION

The traditional lecture course, consisting of a talk given by a lecturer and accompanied by presentation slides, has long since been under sharp criticism [1]. In view of accepted theories of learning, a purely receptive attitude towards learning on the part of students does not appear to facilitate learning, as audiovisual perception offers an effectiveness of only 20% [2]. The course "Electrical Engineering for Mechanical Engineers" (*Grundlagen der Elektrotechnik*, or "GET" for short) at the University of Paderborn is attended every year by more than 400 students in their third semester of mechanical engineering. As GET represents a subject outside of their field, students tend to have difficulties both with the content and with motivation. To provide closer contact to the subject matter and to reduce difficulties in understanding, the idea of the "lecture theater laboratory" was introduced in 2012.

II. THE PRINCIPLE

According to theories of learning, construction and instruction are equally important for successful learning. The learning environment should both offer independent, individual learning possibilities, as well as providing orientation and instruction [3]. New knowledge, in particular the fundamentals of new fields, should not be presented as isolated facts thereby; rather, they should be taught using concrete applications and problems [4]. If these concrete examples are missing, the abstract theories will remain empty for students [5]. Thus, the task of the instructor during the lecture is to introduce students to the topic, to point them in the direction of connections and associations, and to link the topic to other courses or phases in the students' studies [4], [6]. Under those conditions, the lecture is entirely justified as a component of academic education. This is, of course, under the assumption that the lecture is of high quality, so that students can develop an understanding of the subject matter. The appearance and characteristics of a good lecture are dependent on numerous factors, such as the curriculum or the organizational framework. Here, the principle is as follows: active participation of the students is essential for successful learning [3], [5], [6], [7], [8].

TABLE I.
ASSIGNMENT OF COMPETENCES ACCORDING TO [9]

	Competences				
Course Type	***Subject Competence (Cognitive)***	***Subject Competence (Functional)***	***Methodic Competence***	***Social Competence***	***Individual Competence***
Lecture	x				
Seminar	x	x	x	x	
Project Seminar		x	x	x	x
Exercises/ Discussion Group		x			
Tutorial		x			x
Colloquium	x	x		x	x
Excursion	x	x			
University-Internal Practicum		x	x	x	
University-External Practicum		x		x	x

The course GET consists of a lecture course, exercises and a tutorial. Kopf et. al have analyzed several types of academic courses regarding their potential for imparting competences [9]. Table 1 shows that, in order to be able to facilitate the development of the desired competences within the given institutional framework, GET should be expanded to include a university-internal laboratory practicum. Such university-internal labs are used for planning and carrying out scientific experiments. In addition to functional subject competence, the associated group work also imparts social and methodic competences.

This statement is supported by the perspective from those starting their careers in electrical engineering [10]. According to this, a noticeable discrepancy can be seen between knowledge and abilities conveyed at the university and those required by the job market (see Figure 1). Most notably, "Real-World Ability" is insufficiently conveyed at the university.

For the same reason, Bruchmüller and Haug [6] state that "The lecture of the future should include other forms of academic instruction; it needs 'active phases', e.g. the beginnings of laboratories."[1]

[1] „Die Vorlesung der Zukunft soll Anteile anderer Veranstaltungsformen enthalten, sie braucht „aktive Phasen", z.B. Anfänge von Labor." [6]

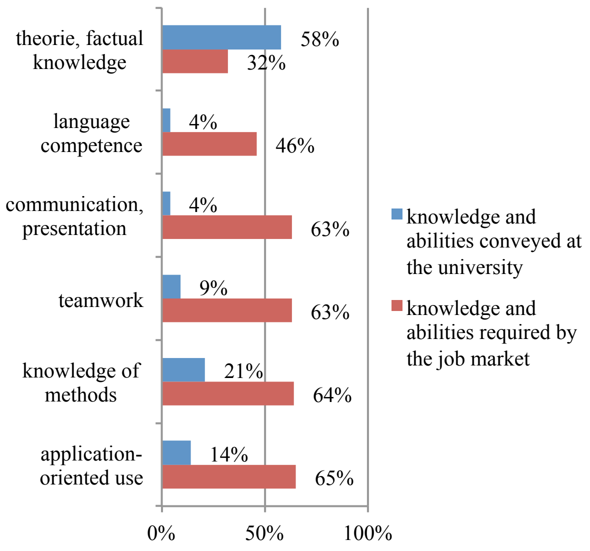

Figure 1. Study According to [10]

How, however, does one design a lecture where students actively participate? Wahl answers this question with the "Sandwich Principle" [8]. This principle represents a learning environment in which collective learning phases alternate with phases of subjective, individual activity. Figure 2 shows the schematic outline of a lecture structured according to the Sandwich Principle.

According to this, the instructor's lecturing is broken up by phases in which the students review the information imparted and can integrate it into existing knowledge structures. Depending on the lecture content, number of participants, etc., the phases of individual activity can be filled using various activating learning methods. One very successful and currently widespread method is that of Peer Instruction (PI) [7]. For this method, students are given a course-specific question testing their understanding together with several possible answers, which each student considers independently before answering. The answers given are then shown in a histogram, so that both the students and the instructor receive feedback on the state of their knowledge. Afterwards, the students discuss their answers in pairs and "vote" a second time on an answer. According to Mazur, the proportion of correct answers always increases following discussion, which he takes to mean that students successfully explain their answers and that they learn from their classmates.

III. IMPLEMENTATION OF THE CONCEPT

To support the learning process, the "lecture theater laboratory" is being developed in the GET course. It allows students to apply the theoretical – and, in engineering studies, often abstract – material practically. In the lecture theater laboratory, the laboratory, lecture, and exercise phases are closely linked to one another, so that it is possible for students to gain practical experience using the equipment as well as deepening their conceptual understanding. As not all areas of the content are suited for experiments, PI is also integrated into the lecture.

To carry out hands-on experiments, groups of three students are given the portable data collection device NI myDAQ [11], a breadboard, and a variety of electrical components to use over the course of the semester (see Figure 3). The NI myDAQ, powered via USB, includes analogue and digital in- and outputs and contains eight instruments for measuring and generating signals. For the PI-method, the PINGO Live-Feedback[2] system, developed at the University of Paderborn, is used [12]. PINGO is especially well-suited for courses with a high number of students; it allows participants to "vote" for their answers using a Smartphone, tablet, or laptop computer.

A. Technical Implementation

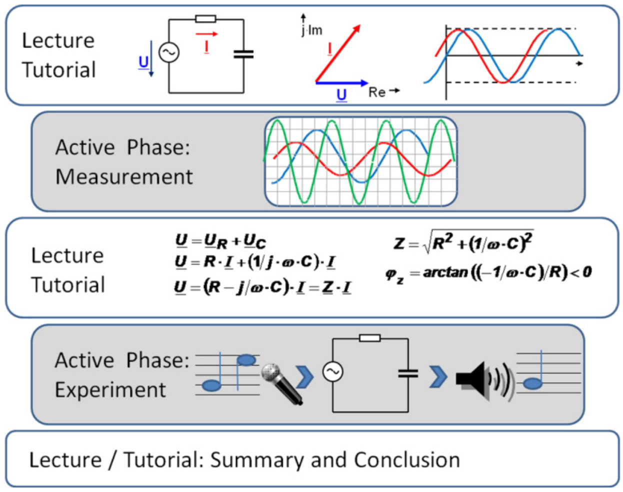

Figure 2. Implementation of the Sandwich-Principle

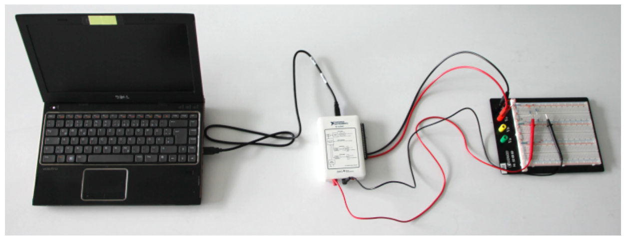

Figure 3. Lecture Theater Laboratory: Experimental Setup

B. Didactic Implementation

The lab assignments have a variety of didactic goals, which are listed and elaborated in the following.

a) Developing Practical Skills In the Use of Diverse Instrument Functions

The students learn during the lecture that current is measured in series and voltage parallel to the component in question. What appears to be simple in practice, however, nonetheless represents a challenge for students who have never used a measuring instrument. The lecture theater lab allows them to practice using such instruments.

b) Visualizing Complex Subject Material

The labs are conceptualized such that complex subject material can be visualized. Following Kautz [13], Kirchhoff's Laws are, for example, demonstrated by the brightness level of light bulbs. Figure 5 shows part of a task in which the brightness of a single light bulb is compared to two bulbs connected in parallel.

2 www.pingo.upb.de

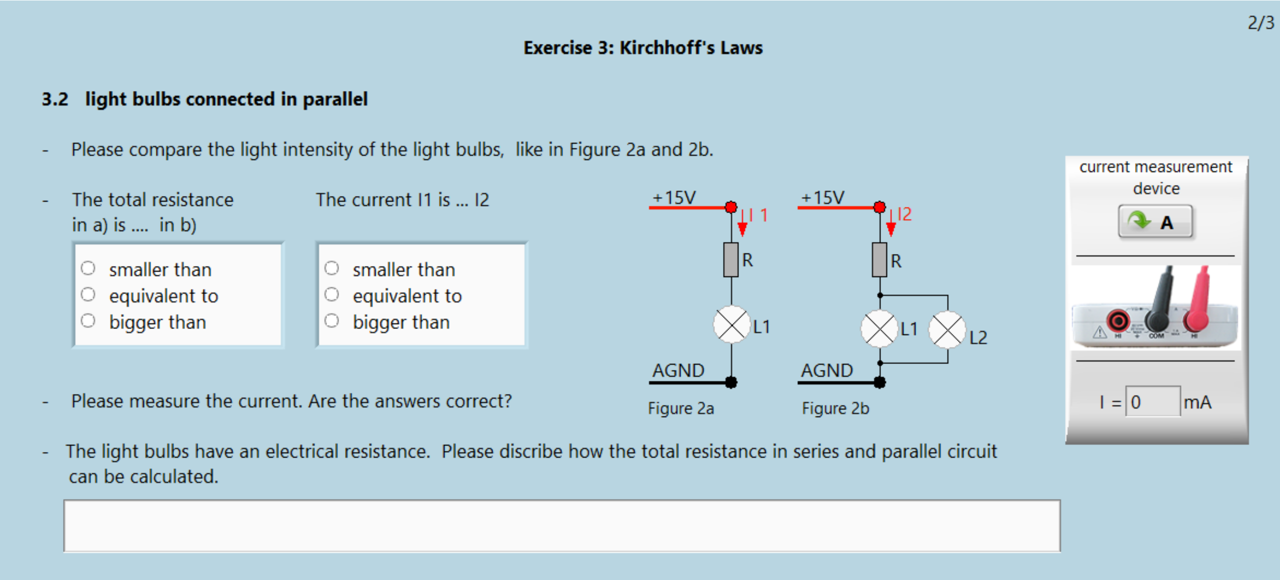

Figure 4. Picture of a Lab Problem

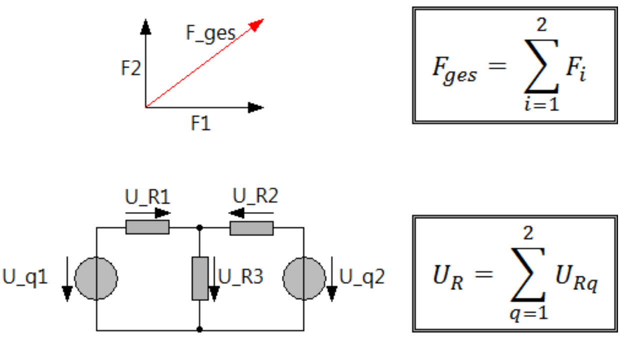

Figure 5. The Principles of Superposition

c) Supporting Conceptual Understanding

Qualitative questions are included in the tasks to encourage conceptual understanding of the lecture content. By analyzing the connection between physical quantities, the students can test their current levels of knowledge. In addition, students are shown analogies. The participants of GET belong overwhelmingly to the field of mechanical engineering, allowing comparisons between superposition principles found in mechanics to those in electrical engineering (see Figure 4).

d) Relevance for the Real World

A further goal is to show students the practical relevance of the lecture content by linking the topics to the real world. As an example, RC-circuits are discussed in the lecture and theoretical values calculated during the exercises. Where such a circuit might be used in practice is, however, often unknown to the students. As shown in Figure 2, students investigate the function of an RC-circuit (low pass filter) by means of different tones. A further example of an application is determining a resistance with a bridge circuit.

When developing the qualitative questions for the PI-method, the “Interactive Learning Toolkit – BQ” (ILT) was used [14]; the questions developed by E. Mazur et al. are available for educational purposes at no cost and have already been put into practice.

IV. CONCLUSION

With the lecture theory laboratory conceived and implemented here, a learning environment has been created which makes it possible to students to actively participate in the learning process. The Sandwich Principle upon which the concept is based combines collective learning phases with phases of individual activity in which students can review the imparted information and connect it to existing knowledge structures. A mixture of construction and instruction allows students to follow their own page and still offers orientation and guidance at the same time.

The lab problems developed here have been explicitly designed for the GET course. They allow students both to gain practical experience using a variety of instrument functions and to deepen their conceptual understanding of the lecture content. By using practical examples, students are shown the connection to real-world applications, so that the usefulness of the theoretical contents is made clear. Both the lab tasks and the Peer Instruction method represent activating methods of learning, which (based on the Sandwich Principle) optimally complement the lecture and involve students in the learning process. Furthermore, the lecture theater laboratory also represents a learning environment that encourages the development of general as well as subject-specific competences. Working in small groups of 2-3 students and the accompanying discussions train teamwork and communicative skills.

V. DISCUSSION AND OUTLOOK

The concept explained here will be tested for the first time during the winter semester 2013/2014. At the time of publication, experiences with the PI method using PINGO have thus far been positive. Students participate to a high degree and constructively discuss lecture content.

In order to come to a conclusion about the influence and the sustainability of the activating learning methods, a nuanced evaluation is necessary. The first run-through of the lecture theater laboratory will also offer a perspective on the level of both difficulty and acceptance of the new working methods, as well as possibly revealing necessary changes to be made to the materials.

The evaluation will be completed during the semester in the form of a survey using PINGO, concerning the usefulness and level of difficulty for the individual lab tasks. Additionally, the solutions of the written exam at the end of the semester will be analyzed with in relation to various competence levels and compared to previous exam sets. The goal is to develop a system which can be used to detect the development of competences as a result of the lecture theater laboratory.

As part of a more detailed evaluation, the possibility is under consideration to split the students into two groups, one of which would attend the classic lecture and the other of which would attend the lecture theater laboratory. The solutions in the written exams could also be compared in this case. A further possibility would be the adaptation of the type of exam administered, so that, in addition to testing subject competence with a written exam, other general competences could be tested via short practical tests. Under suitable conditions, a switch to purely practical or oral exams is also conceivable.

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