Design of Tutorial Activities and Homework Assignments for a Large-Enrollment Introductory Course in Control Systems

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Abstract: This paper presents an integrated design for an undergraduate introductory course control systems at Hamburg University of Technology (TUHH). The core features consist in combining traditional lecture and student led tutorials with weekly homework assignments which have been designed to encourage continuous learning efforts through a review of previous tutorial sessions and a preview on forthcoming lectures. The homework concept is implemented via an open source e-learning platform. A portable DC motor, available through the university library system, serves as an experimental setup, which is tightly integrated into lecture, tutorials and homework. Details on the implementation of the proposed design are given and it is evaluated based on data, which is e.g. collected by evaluation forms completed by students at the end of term.

Keywords: Introductory course, e-learning, homework assignments, take-home experiments, student led tutorials.

1. INTRODUCTION

Subjective impressions during consultation hours and exam corrections often reveal that students in engineering fail to establish a robust conceptual understanding of the main lecture topics. This has been confirmed by various studies, see (Kautz, 2011) and references therein. We report on integrating tutorials and homework in an introductory course on control systems with the aim to increase the student/student and -/tutor interaction to help students develop a functional understanding of the core ideas.

Most courses at TUHH follow a relatively rigid structure of lectures and tutorials. Recently, innovative teaching methods, such as problem-based learning (PBL) (Perrenet et al., 2000), have emerged. However typical large-enrollment lectures with several hundreds of students are usually not designed based on such models. The academic year is divided into two terms, which last from April until September for the summer semester (SuSe) and October until March for the winter semester (WiSe). Courses are held in general once a year. Exams are taken during the last two to three months of each term. Most commonly, the final exam determines to the entire grade awarded for a course, weighted by its credits’ worth. Each credit (ECTS — European Credit Transfer System) denotes 30 h of labor, encompassing everything from attendance time to exam preparation.

The introductory course to control systems is mandatory for a variety of majors at TUHH ranging from mechanical, electrical and process engineering to logistics and mobility, encompassing more than 450 students each winter term (cf. Fig. 2). Curricula are designed for students to take the course during their fifth semester and students are awarded 6 ECTS for successful completion of the exam. Having completed at least three mathematical courses on linear algebra, differential and integral calculus, as well as courses on the modeling of mechanical and electrical systems, the students are in general well prepared for basic control systems material. The fact that only about half of the students have taken Systems Theory requires special attention throughout the term. The extensive use of MATLAB for exercise problems and during lectures poses a further challenge to students.

After a short introduction on signals and systems, the course covers the basic principles of feedback and heuristic controller design. Further chapters are dedicated to classical control techniques, covering root-locus- and frequency-response-based methods. A brief introduction to digital control is given at the end of term. Table 1 provides an overview of the course’s timetable. The course is divided into lectures and tutorial classes, each of 90 min. length. They are presented on the blackboard, imposing a natural limitation on presentation speed and style, thereby making it easier for students to take notes. The lecture
Table 1. Course’s timetable.

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notes are also available as a 250-page printable PDF document, containing all content of the lecture, exercise problems and elaborate solutions. During terms prior to WiSe 2011/2012, the tutorial classes were conducted in a large lecture hall and up to three small tutorial sections led by academic staff members. Prior to each tutorial, students were expected to solve a set of problems with the help of the lecture notes. The tutorials had been meant to take the form of in-depth question-and-answer sessions specific to those problems. About a quarter of the tutorial problems were connected to the modeling and control of a DC motor in simulation. In addition, students were able to borrow a DC motor “suitcase experiment” set from the institute (see Fig. 1), connect it via USB to their personal computers and perform real-time experiments at home.

In the past, the course was rated quite highly (about 2 on the scale from 1 [highest] to 5 [lowest]) in end-of-term evaluations. However, it became apparent from consultation hours, exam corrections and evaluations (cf. Fig. 1) that some issues require attention. In conjunction with comments and discussions with students, it was revealed, that theoretical depth, when not clearly related to practical applications, may be perceived as difficult and students may not be able to identify connections to future professions on their own. This can encourage a habit to concentrate on passing the exam as the sole entity by which the final grade of the course is derived. As a result of the evaluation of terms preceding WiSe 2011/2012, several objectives for a modification of the course design have been derived:

- Active participation of students in the tutorials,
- Greater emphasis on practical examples,
- Level background knowledge among students during early tutorials/lectures,
- Promotion of continuous and collaborative learning efforts.

These objectives are constrained by several factors:

- Unchanged (perceived) student workload,
- Simple organizational structure that is easy to communicate,

Fig. 1. Evaluation results:\(a\) "With respect to my future profession the learning goals of the lecture were clear.", (b) "My background knowledge was sufficient for the course.", (c) "I solved the exercises on my own."

Fig. 2. Number of enrolled students

Fig. 3. Average score and participants in homework assignments for the WiSe 2012/2013:

- Availability of resources (space, personnel, etc.)

3. OUTLINE OF THE MODIFIED COURSE DESIGN

The modifications are based on the idea of interconnecting the learning experiences from lecture and tutorial sessions more seamlessly via weekly homework assignments, submitted online, and smaller-size student-led tutorial groups. The purpose of the homework assignments is to promote a continuous learning effort by engaging students with the material prior to the actual lecture, as well as by requiring the students to review contents of the tutorial problems. Moreover the students are motivated to commit to learning groups to check their submitted homework among themselves. These learning groups as well as the small tutorials were meant to foster collaborative learning. Changes were implemented over the course of two terms, starting with student-led tutorials in WiSe 2011/2012 and refining the homework concept in WiSe 2012/2013. Details are given in the sections below.

To improve the practical understanding of the students, the DC motor experiment is seamlessly integrated into lecture notes and tutorial problems, as well as into dedicated homework assignments. The overall course design can be visualized in a simple diagram as given in Fig. 4.

3.1 Homework Assignments

To motivate continuous participation of the students during lectures and tutorials a new homework concept, consisting of 12 weekly homeworks, is introduced. For each successful submission students are awarded 1% of the final grade, amounting to a total of 12%. We expect students attending tutorials and lectures regularly to complete the homework assignments in a about 30–40 min. There are

a) Clear connection to future profession
b) Sufficient background knowledge
c) Tutorial problems solved independently

2 Scoring scheme: 5.0 bad/not conform, . . . , 1.0 very good/conform. The number of answers and standard deviation are shown.
two different types of homework assignments, 'pre-lecture assignments' and 'post-exercise assignments'. The former are intended to prepare students for forthcoming lectures; the latter to help them review essential learning goals and extend the tutorial exercises. In general a pre-lecture assignment and two post-exercise assignments are to be submitted each week. The tutors are involved in the homework design by testing and giving feedback.

Pre-lecture assignments The aim of Pre-lecture assignments (Kolari and Savander-Ranne, 2007) is that the students deal with upcoming subjects on their own in preparation of the lecture class, e.g. by reading the lecture notes. Thus, the lecture time can itself be used more efficiently, because the lecturer can focus on the more difficult aspects trusting that students have already acquired the basic facts. The students can follow more easily if they recognize elements, they have already studied themselves, which effectively deepens the understanding process by recapitulation. Pre-lecture assignments should in general require little effort, in order to avoid frustration. Therefore, page numbers, even specific paragraphs of the lecture notes necessary to solve a task are given explicitly, setting very clear expectations. Continuous adaption of the assignments are required whenever the lecture deviates from the timetable. An extensive task catalog, which has been designed pre-term is recommended. Below, an example of a pre-lecture assignment from the fourth week is given. The question is of the multiple-choice type, which reduces the students' efforts required to answer and facilitates possibilities to identify misconceptions by quick data analysis.

Example 1. Pre-lecture assignment. Which of the following statements about 'system type' is correct (lecture notes pp. 71-73, Definition 2.1, Figure 2.16)? The system type is determined by...

(1) the largest power of $s$ in the denominator of the transfer function $L(s)$.

(2) the number of integrators in the transfer function $L(s)$.

(3) the difference between the number of poles and zeros of a transfer function $L(s)$.

(4) the largest integer $k$ such that $s^k$ is a factor of the denominator of $L(s)$.

An explicit reference to the definition of 'system type' is given, which is equivalent to the fourth answer. Here, correct answers are identified by italics. The second correct answer requires some degree of reflection on previously learned material to link the course material during the entire term. The first and third answer possibilities recap the definitions of 'system order' and 'pole excess', such that the students implicitly learn to distinguish the new definition 'system type' from those already known.

Post-exercise assignments In tutorials, the mostly theoretical lecture content is applied to problem tasks. The post-exercise assignments are designed to reinforce those subjects by questions that build on the existing exercise tasks, mostly literally extending a given problem divided into subtasks a) to c) by a further subtask d). The basic idea is that if students have attentively participated during tutorial classes, the post-exercise assignments should be relatively easy. They are mostly open questions, pointing out the problem from the lecture notes which they refer to.

Example 2. (Post-exercise assignment). Revisit Prob. 2.4). Consider a plant with transfer function $G(s) = \frac{2}{s(s+1)}$. Propose a controller for this plant that simultaneously fulfills all the following conditions: (here $\sigma(t)$ denotes the unit step)

(i) achieve zero steady state error for $d_u(t) = \sigma(t)$, $r(t) = d_u(t) = 0$.

(ii) achieve zero steady state error for $d_u(t) = \sin(t)$, $r(t) = d_u(t) = 0$ and

(iii) stabilize the closed loop system shown in the figure.

In Prob. 2.4 referred to in the assignment, it has been required to find a controller, that satisfies only objectives (ii) and (iii) for a plant $G(s) = \frac{2}{s(s+1)}$. Knowing that to satisfy (i) the controller needs to incorporate an integrator and that for (ii) and (iii) it does not matter whether the integrator is contained in either plant or controller, simply the same solution as in Prob. 2.4) can be adopted and no tedious calculations are required to obtain full marks.

3.2 Implementation in the E-learning Platform ILIAS

Paper-based homework assignments during the previous term have suggested that online-tests facilitate a more economical use of teaching assistant time. They also enable students to freely migrate between tutorial groups, which students have previously been required to register and stay in, as they functioned as the submission hub.

The presented homework concept has been implemented on the e-learning platform ILIAS\(^3\). ILIAS is an open source learning management system (LMS), developed at the University of Cologne/Germany. Although ILIAS is not the standard LMS used at TUHH, it is used for its increased flexibility. It is also easily coupled to stud.IP, which is the standard LMS used at TUHH. ILIAS offers the possibility to construct objects called ‘question-pools’ to collect and organize sets of questions, that can then be easily assigned to 'test'-objects. Each homework assignment has been realized in one 'test'. For each test, a set of individual properties can be configured. In the implemented setup e.g. options have been chosen such that for multiple choice tests order of possible answers is randomly generated each try. A test can be repeated as often as desired while it is online, and previously given answers can be seen. Only the responses given last are graded. Multiple-choice questions are automatically

http://www.ilias.de
corrected and only completely correct answers are marked as correct. Open questions need to be corrected manually, which was done by the student tutors. For this purpose, ILIAS also provides an extensive role and permission management system. The final results are only visible when manually activated.

The tests are online between two lectures for almost a week. As its main goal, this form of online-tests encourages working in groups as well as continuous self-assessment and learning. Cooperation between students when solving homework problems is encouraged, and the possibility that some students may copy answers from others is taken into account and considered to be outweighed by the benefits.

3.3 Student-Led Tutorials

Tutorials led by more experienced students are relatively common in higher education throughout several disciplines for several reasons (Volder et. al., 1985), (Magin, 1995), (Moust and Schmidt, 1994). They allow for smaller groups, which facilitates an activation of the attendees. This reduces passive listening found in large lecture halls, since student tutors as opposed to staff members are more likely to alleviate the fear of asking questions. By providing more individual attention for each participant, smaller groups encourage increased interaction, thereby enhancing the learning process. In the case of highly inhomogeneous levels of background knowledge, smaller size student led tutorials can help students catch up quickly.

The above reasoning has influenced the design of weekly tutor meetings led by staff members to focus on social skill development to a similar degree as on technical training. Weekly meetings have been directed by two staff members as well as the professor to engage tutors in discussions about key learning goals and motivational strategies. In these meetings detailed reports of the tutorials were given by the tutors. An important tool for providing effective teaching is to identify and eliminate a student’s misconceptions about fundamental technical issues (Brose and Kautz, 2011), (Kautz, 2011). The tutors need to be trained in the observation of these misconceptions and report them. Future exercises can then be designed with these in mind. This knowledge can also be fed back to the design of weekly homework assignments in the form of Just-in-Time-Teaching (JiTT) (Novak et. al., 1999). The Center for Teaching and Learning of TUHH supports tutor training by professionally held seminars, that can be taken for academic credits. Furthermore, staff members have attended tutorial sessions to further evaluate and improve on the quality of peer teaching by giving the tutors feedback and suggestions. As a regular element of the meetings, role playing scenarios have been conducted, where each time one of the tutors is appointed to conduct part of a tutorial, while all the other attendees including the staff members assume the roles of the students. A simple, yet effective, tool to secure consistent dissemination of organizational information consists in recording the results of each tutor meeting in writing. This can also help ensure the conveyance of a consistent set of technical learning goals in the tutorials.

During WiSe 2011/2012 student-led tutorials have been conducted under the premise that they remain question-and-answer sessions expecting the students to attend well prepared. Since WiSe 2012/2013, in the light of an increased student workload, students are expected to prepare questions regarding the task description rather than its solution, while detailed solutions are worked out during sessions.

3.4 Motor Assignments

Due to the large number of students, on-campus labs for this course have so far not been established. Instead, a DC motor suitcase experiment was introduced four years ago. A set of institute-built DC motors can be borrowed by students motivated to perform real-time experiments at home. As motor tasks were published in a separate document, integration in the general course was lacking. The lending process was cumbersome and students suffered from insufficient practical experience with MATLAB. Consequently, only very motivated students took advantage of the offering.

The new concept enhances the central role of the DC motor in the course design. Early in the lecture, a simple model of the DC motor is introduced. The subject is intensified in the tutorial classes, where the modeling is discussed under different points of view and basic parameter identification is performed. In addition, the tasks concerning the motor have been revised, simplified and integrated in the regular set of exercise problems. The motor tasks are discussed by means of prerecorded experimental data and students are encouraged to do the real-time experiment themselves. In addition, two long-term homework assignments dedicated to the motor have been devised, by which students can receive bonus points.

The number of motors available has been increased from 30 to 60. To reduce organizational effort, the lending process has been taken over by the university library with which students are well familiar. Students are explicitly asked to work in groups, since 60 devices are still too few for 500 students. An additional introductory lecture has been offered to introduce MATLAB and Simulink for control systems, showing the relative ease by which DC motor experiments can be performed at home. An online forum has been set up, in which a tutor answers as ‘trouble shooter’ to all practical questions.

3.5 Weekly Time Line

A weekly schedule is shown in Fig. 6. The lecture takes place on Fridays and 21 tutorial sections are spread over the whole week. Each Friday night a new homework is taken online, whose post-tutorial assignments refer to the exercise problems of the previous week and pre-lecture assignments refer to next week’s lecture. Therefore, the submission deadline is set to Thursday night of the upcoming week. Student tutors are given a week for grading until the results are published. Each Wednesday the tutor-meeting takes place.

4. EVALUATION

Homework Assignments  Homework participation levels are reported in Fig. 3. Even though the number of participants degrades from 650 to 450 over the course of the
to distinguish between pre- and post-assignments due to software restrictions. Moreover in the closed questions in the end-of-term evaluation analyzed in Fig. 7, the homework were rated helpful in general, but especially the pre-assignments seem here to have the desired effect. Concerning the self-contained use of MATLAB the evaluation shows the major need of reform. The free-text responses support this. Although there the introductory lecture for MATLAB and Simulink was evaluated as "very helpful", "great", "good starting point", there was also the wish for more.

4.1 Student-Led Tutorials

Student led tutorials are generally regarded as a success in their implementation during WiSe 2011/2012 and 2012/2013 for several reasons. By the majority of the students, they are not perceived as less instructive than staff-led tutorials (cf. Fig. 8), which can be seen to receive much lower ratings (as in WiSe 2009/2011). Students also feel to be under better guidance due to the smaller tutorial groups (cf. Fig. 9).

Despite a surplus of about 100 in the number of enrolled students (cf. Fig. 2) in WiSe 2012/2013 over 2011/2012, tutorial attendance levels have started at only slightly higher levels in WiSe 2012/2013. Taking this into account, the attendance has remained on a higher level in terms of absolute values as well as showing less relative decrease (cf. Fig. 10(b)). Tutorial no. 1 of WiSe 2011/2012 is considered an outlier, since in that session students had to register for the homework assignments, which was not necessary in WiSe 2012/2013. This may possibly be due to the change of strategy, not expecting the students to attend with exercise problems fully prepared. Ultimately, we believe, that this has led to less frustration and a more constructive atmosphere during classes.

It turns out, that technical skill — though a solid level should be present — seems to be less elementary than a tutor’s reliability and ability to engage him- or herself and others in communication. This appears to be equally true
Implementing new concepts in large-enrollment courses requires immense organizational effort. It is vital to maintain organizational simplicity and consistency for both students and tutors. Student led tutorials offer a comprehensive student support with improved tutor-student ratio and comparable learning effects despite possibly inferior technical abilities of the tutors. E-learning platforms such as ILIAS provide the possibility to efficiently manage homework tasks. Pre-lecture assignments enable students, to benefit more from each lecture and post-exercise assignments motivate to recap and deepen tutorial problems. In general, the implemented concept is an improvement, which is shown both objectively and subjectively via evaluations. Further data from exam results and long-term evaluation will further facilitate an improved implementation. Future modifications should be considered one at a time and carefully evaluated with respect to their educational value, e.g. by concept inventory tests.

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