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Opportunities of digital teaching in process control: flip the classroom, provide a level playing field, and integrate external experts

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Abstract

After serval periods of remote teaching in the COVID-19 pandemic, many academic institutions are working on concepts to transfer the lessons learned about digital teaching into their didactic concepts. In this paper, we present a didactic concept for courses with student groups of heterogenous educational background. It is based on a self-paced learning phase with self-study materials, a flipped classroom session for interactive problem solving in interdisciplinary student groups, an exercise session for more complex problems, and a student project. An important key feature is that (1) the students can learn according to their educational background in the self-paced learning stage and teach each other in the other parts of the course. Additional features are (2) the maximized share of the student-staff contact time spent on cooperative problem solving and (3) the collaborative development of teaching materials with external experts. The concept was implemented within our course on process control systems. The results are illustrated via the example of a digital teaching module for hybrid semi-parametric modeling.

Nach mehreren Phasen der Fernlehre in der COVID-19-Pandemie arbeiten viele akademische Einrichtungen an Konzepten, um die Erfahrungen mit der digitalen Lehre in ihre didaktischen Konzepte zu übertragen. In diesem Beitrag stellen wir ein didaktisches Konzept für Kurse mit Studierendengruppen mit heterogenem Bildungshintergrund vor. Es basiert auf einer Selbstlernphase mit Selbstlernmaterialien, einer Flipped-Classroom-Sitzung zur interaktiven Problemlösung in interdisziplinären Schülergruppen, einer Übungseinheit für komplexere Probleme und einem Schülerprojekt. Ein wichtiges Hauptmerkmal ist, dass (1) die Studierenden in der Selbstlernphase entsprechend ihrem Bildungshintergrund lernen und sich in den anderen Teilen des Kurses gegenseitig unterrichten können. Weitere Merkmale sind (2) die Maximierung des Anteils der Kontaktzeit zwischen Studierenden und Lehrkräften, der für kooperative Problemlösungen aufgewendet wird, und (3) die gemeinsame Entwicklung von Lehrmaterialien mit externen Experten. Das Konzept wurde in unserer Lehrveranstaltung über Prozessleitsysteme umgesetzt. Die Ergebnisse werden am Beispiel eines digitalen Lehrmoduls zur hybriden semiparametrischen Modellierung dargestellt.

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1. Introduction

Just as for many other chairs and professorships, the COVID-19 pandemic demanded a transfer of teaching concepts into the digital space from the chair for Process Control Systems (PCS) and the Process Systems Engineering (PSE) group at TU Dresden. Many different lectures, exercises and even practical work of different class sizes (10 to 150 students) had to be transferred into a digital format. To achieve this, various teaching concepts have been adopted in synchronous and asynchronous formats, with videos or life lectures, with questions & answers (Q&A)-based or life exercises, etc. with varying degrees of success. Especially in small sized lectures with up to 30 students an asynchronous flipped classroom approach proved to be a valuable approach providing advantages over the previous conventional teaching style.

The regulatory relaxation of the pandemic related measures then called for a transition of these online concepts into the regular, attendance-based teaching context of our universities based on lectures, exercises and practical work. We also wanted to take further advantage of the digital teaching formats and to continue to use the newly developed teaching materials. Therefore, we chose the lecture "Simulation und Optimierung" (SimOpt, engl.: Simulation and Optimization) in the module "Prozessführungssysteme" (engl.: Process Control Systems) as a use case to continue the development of our teaching concepts. SimOpt is an advanced interdisciplinary lecture consisting of lectures, exercises and a student project, which has to be carried out by the students in interdisciplinary groups of 3-5 students. In the following, the teaching concept and the results of the first implementation steps of our digital fellowship "Digitale, interdisziplinäre Lehre im MINT-Bereich (LIME) - Ausbildung der Ingnieure von Morgen" are presented.

2. Requirements and Concept

The lecture SimOpt aims to achieve two main objectives:

1. Develop advanced skills in process control
2. Develop soft skills for interdisciplinary collaborative work in process control projects

To achieve these goals, the lecture is aimed at students in the study programs "Process Engineering and Natural Materials Technology", "Electrical Engineering", "Mechatronics", "Renewable Energy Systems" and "Information Systems Engineering" as an elective course. In past years, SimOpt did consist of some lectures and exercises to convey knowledge and to provide a level playing field for the heterogeneous group of students. Furthermore, it contained a student project based on rather open project tasks, which was done in interdisciplinary groups of 3-5 students. The student project aimed to simulate a problem-solving task in an industrial environment by providing a real-world monitoring or control problem provided by the Process-to-Order Lab (P2O-Lab) or by an industrial partner. Important key features of the lecture were and will still be

1. its interdisciplinary character,
2. the small sized classes, and
3. its advanced level.

In LIME, we aimed to rethink the way we provide a level playing field for the students, while maintaining the student project. The new concept is based on digital teaching modules, which are used to provide knowledge in a flipped classroom approach. For this purpose, 12 individually digital teaching modules were designed addressing topics like e.g.: the basics of first principles modeling, hybrid semi-parametric modeling, multiple-input-multiple-output control (MIMO) and model-predictive control (MPC). Each digital teaching module consists of one

- a self-paced learning phase with self-study materials, including
    - 1 motivational video
    - 3-5 teaching videos recorded with a lightboard explaining the most important methods and concepts
    - ~10 A4 pages of script providing further content for deeper understanding

- a flipped classroom session consisting of
    - Q&A session
    - 1 problem, which must be solved in interdisciplinary project groups of 3-5 students with help of the lecturer applying MATLAB
- and an exercise session based on
    - 1-2 problems, which must be solved in the interdisciplinary project groups of 3-5 students applying MATLAB

In parallel to the teaching modules, the students work on

- a student project with a complex problem-solving task which spans the entire semester.

Each student group also serves as an interdisciplinary study group. The concept described above does allow to address the three key features of the SimOpt lecture in a convenient manner.

Firstly, the digital teaching modules provide a measure for the interdisciplinary composition of the student group. Students of the study programs "Electrical Engineering", "Mechatronics", etc. can usually be expected to be highly skilled in control design and programming but lack knowledge regarding dynamic modeling of process systems. Meanwhile, "Process Engineering and Natural Materials Technology" students usually have a higher skill level in process modeling but lack knowledge in control theory. The self-learning phase based on the Self-paced learning phase does allow these individual groups of students to focus on their particular learning fields. Furthermore, students can skip content and topics they feel already very familiar with. In the flipped classroom sessions and the exercises, emphasize is put on the application of the knowledge and the interdisciplinary exchange within the project groups. Thus, this teaching style does allow to provide a level-playing field while accounting for the needs of the individual groups of students.

Secondly, the flipped classroom approach allows to make the most of the small sized class. In the past years, it became widely accepted, that flipped classroom concepts provide a great tool to attain mastery for students [1,2]. Lewin et al. [3] argue that students should be allowed "to experiment, get things wrong and understand why". Furthermore, they state that the student-staff contact time should mostly be used to work on problems cooperatively. The staff members should become mentors and motivators. Since this is easier to achieve with a high staff to students' ratio, this suits the SimOpt lecture well. In addition, students begin working together in interdisciplinary project groups early on through the Flipped Classroom approach, start to transfer knowledge within the group, and learn to understand the competency profile of the other students in the group.

Thirdly, the development of digital teaching modules easily allows the integration of new topics from research, which can potentially be provided by external experts. Hence, this provides a suitable framework for an advanced lecture. A pleasant side effect is that this approach does allow to distribute the preparation workload for the teaching materials across institutions if the materials are published as open educational resources (OER) by the contributing partners.

3. Implementation of the Concept in the Digital Fellowship LIME

The chair of PCS and the PSE group is revising the lecture SimOpt in the context of a tandem Digital Fellowship funded by the Sächsisches Staatsministerium für Wissenschaft, Kultur und Tourismus (SMWK). The objectives of this funding program were [4]:

- support the development of digital teaching and learning competencies
- development and testing of innovative teaching and examination methods as well as digital teaching methodologies and tools
- establish Open Educational Resources (OER) in the teaching practice

he provided budget does allow for purchase of additional equipment and materials for our recording environment for the teaching videos. Furthermore, we are able to pay external experts and student workers who support us with the development the teaching materials. For LIME, we did retrofit the Usability for Process Industries (UPI) Lab of the chair of PCS. The lab was already equipped with furniture and recording equipment. Therefore, only little additional equipment was needed like e. g. microphones and bodypacks for the recording. Furthermore, we contacted ten external experts in the field of process control asking for contributions to modeling, process monitoring, process control, etc. to date. The experts were chosen based on their reputation in the related topic. For example, Mr. von Stosch (see [5]) contributed as a highly ranked expert in the field of hybrid semi-parametric modeling for this particular topic in our curriculum. Figure 1 presents an overview on the contributions of external experts to LIME. We received nine answers to our initial contact e-mail. Seven of the experts were in principle interested to contribute to project. Currently, the contribution of three experts is fixed while we are still in negotiation with four additional experts. One expert did not answer to our e-mail, and two did reject to contribute due to the conditions of the contract. Overall, we recognized a reasonable interest in collaborative digital teaching modules. Hence, we believe this concept provides a framework of high potential for collaborative teaching and exchange of teaching materials in the future. The funding of the Digital Fellowship furthermore did allow us to offer a compensation to the external experts. Overall, it can be stated, the compensation did not seem to be the main reason for the experts to decide whether to contribute or reject. The major reason for a rejection was the time, which would have had to be dedicated to the development of teaching materials. Staff members of relevant expertise were paired with the external expert to support them by answering questions about the content and coordinated the formatting of the provided materials with the student workers. The student workers under supervision of the staff

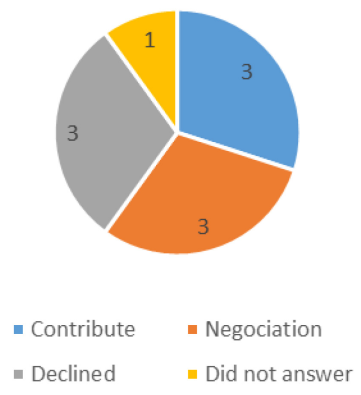

Fig. 1: Contribution of external experts to the digital teaching project LIME-

members were responsible for setting up the recording environment including software tools etc. Furthermore, they did the recording with the staff members or the external experts in our recording environment. Afterwards, they are responsible for the video editing. Furthermore, the staff members, the student workers and the external experts developed problems to be solved in MATLAB. All materialsare created under a Creative Commons license[1] and will be reusable as open educational resources for the TU Dresden, the external experts and other interested institutions or entities.

4. Example - A digital teaching module on hybrid semi-parametric model

This section provides an example for a digital teaching module. For the teaching module on "hybrid semi-parametric modeling", we collaborated with Dr. Moritz von Stosch. Dr. von Stosch provided us with

- a motivational video on hybrid semi-parametric modeling,
- a lightboard sketches, which we adjusted for our purpose,
- a script on hybrid modeling, and
- two exercise task, which we adjusted to apply them within the flipped classroom session and the exercise session.

Figure 2 shows one of the lightboard sketches we derived. On the left side, the sketch shows an open tank system, where water can be fed actively via an input volume flow and is evapo-

[1] https://creativecommons.org

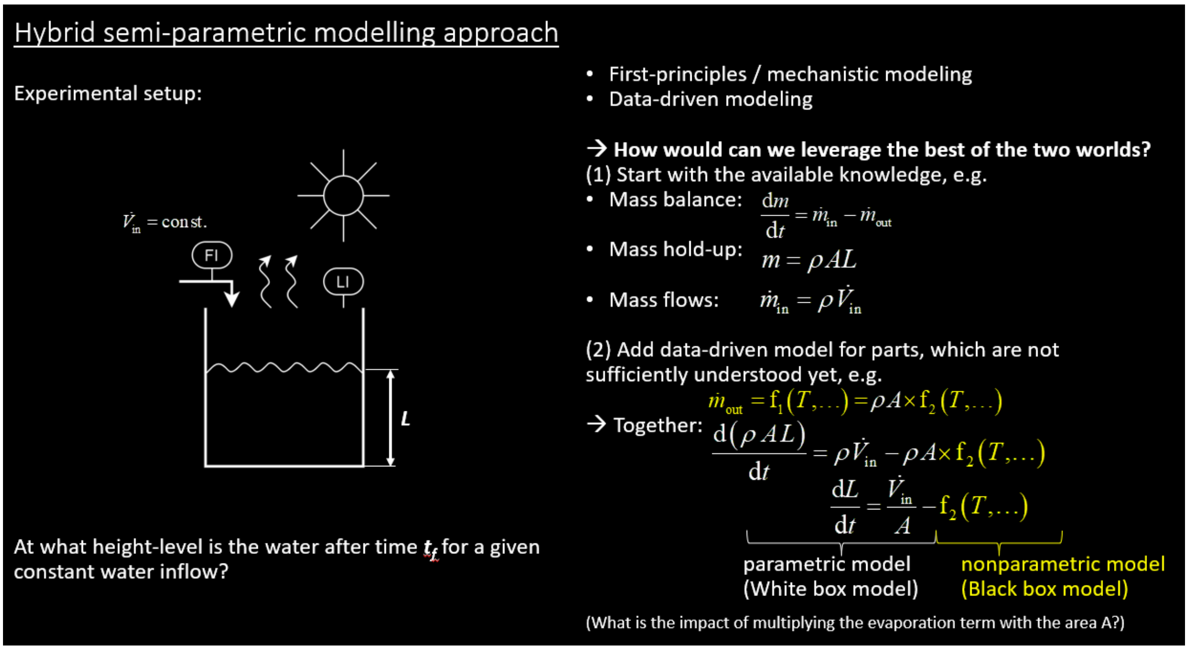

Fig. 2: Example of a lightboard sketch on hybrid semi-parametric modeling

rated by the sun. On the right side, the basic idea of hybrid semi-parametric modeling is presented. Parametric models based on first-principles are combined with non-parametric, data-driven models. Based on the lightboard sketches, we recorded videos with our lightboard.

Figure 3 provides an impression of the style of the videos and provides a link to the example video on YouTube.

For the self-paced learning phase, students were provided with the motivational video, 5 lightboard videos, and the script. These materials were provided via the learning platform OPAL. Figure 4 presents the structure of a teaching module on OPAL.

In the flipped classroom session, firstly a Q&A session was carried out. In the particular Q&A session on hybrid semi-parametric modeling

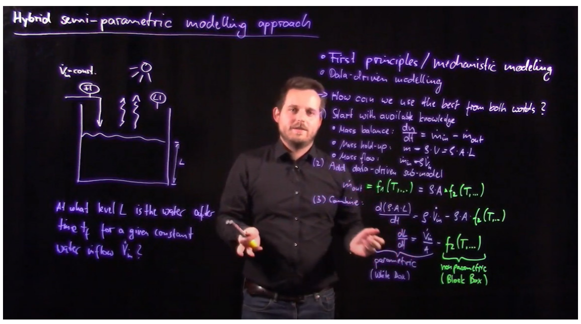

Fig. 3: Screenshot from a lightboard video (see: https://youtu.be/Z8JZm-f1tbQ)

e.g. a question was asked on how parameter identification of hybrid semi-parametric models can be done.

Afterwards, the students were presented with the first problem, which was based on the first exercise task provided by Dr. von Stosch. Via the OPAL platform, the students were provided with a dataset relating different cross-sectional areas, times, and temperatures to the evaporated water volume in open tank systems similar to the system presented in Figure 2. Now, the students were asked to develop a model capturing the behavior described by the dataset. An important feature of the dataset is that it is too small to apply pure non-parametric, data-driven modeling approaches. Furthermore, the amount of available knowledge about the system is too low to develop a parametric, first-principles-based model. These challenges were elaborated in an interactive discussion among students and between lecturer and students as well as through several iterations of trial-and-error. Furthermore, a suitable hybrid semi-parametric model architecture, its implementation, and its validation based on a test dataset were discussed interactively and developed in MATLAB. The result is a nonlinear algebraic equation (NLAE) constructed from parametric and nonparametric model parts.

In the exercise session, the students were presented with a more complex system based on a continuous stirred tank reactor (CSTR). In addition, again they were provided with a training and a test data set. This problem is more complex since the solution envisaged is an ordinary differential equation (ODE) system, developed from the mass balances for the different reacting components. The reaction rate is captured by a non-parametric sub-model. This problem was again processed in the in the interdisciplinary project groups and interactively discussed with the lecturer.

Overall, we were able to significantly reduce the preparation time to integrate this new topic into our curriculum. Furthermore, we produced reusable teaching materials, that will be licensed under creative commons and therefore will be reusable by our external partners as well. Furthermore, we experienced very interactive and hands-on flipped-classroom and exercise sessions with our students.

5. Conclusion

The COVID-19 pandemic accelerated the adoption of new teaching concepts like digital teaching materials (e.g.: lecture videos, etc.) in many universities. The same is true for the chair of PCS and the PSE group at TU Dresden. After adopting multiple different teaching concepts for different lectures, a flipped classroom approach supported by digital teaching materials demonstrated its high potential especially for small to medium sized classes. It allows to maximize the student-staff contact time dedicated to problem-solving instead of an information transfer. Furthermore, it unlocks the integration of contributions by external experts into the lecture program. This is especially interesting for advanced courses, since new digital teaching modules on recent research topics can be developed in collaboration with the external experts. In addition, this approach can mitigate the workload of the teaching staff since the workload can be distributed across different institutions. The overall interest of the experts contacted within the Digital Fellowship LIME into the collaborative development of digital teaching modules has

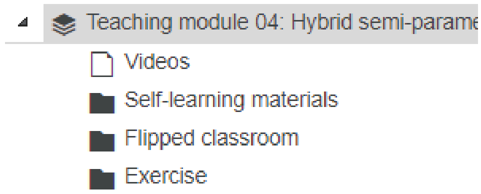

Fig. 4: Structure of a teaching module on the learning platform OPAL

been found to be reasonable. Therefore, we are convinced that the approach of LIME shows potential for a wider adoption. Such collaborative development of teaching materials could be hosted by partnering chairs within universities or by the communities of the particular disciplines. The major reason to reject a contribution to LIME were missing time resources. We expect this issue to be mitigated by the basic concept of collaborative development of teaching materials, but the development of the new concept and the alignment on common topics, structures, and styles make the initial steps challenging. But the experience with the preparation of teaching modules on e.g. hybrid semi-parametric modeling was promising. We were able to significantly reduce the preparation work for a new lecture topic within our group, produced self-paced learning materials that are reusable by us and our partners as well, and experienced very engaged flipped-classroom and exercise sessions with our students.

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