Digital Teaching and Learning Projects in Engineering Education at Technische Universität Berlin

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Abstract

With more than 33,000 students primarily in engineering and architecture, mathematics and natural sciences, the Technische Universität Berlin is one of the largest technical universities in Germany. The teaching staff comprises only about 350 full-time professors, about 30 junior professors, few full-time and part-time lecturers, but nearly 2,700 scientific research and teaching assistants.

This leads to challenges in its engineering education – particularly in the highly frequented STEM-courses during the freshman year. Current challenges for teaching and learning are caused by recent structural and curricular changes of the undergraduate and graduate programs. This contradicts with partly traditional learning environments, in particular big classes with 1,000 or more students in introductory STEM-lectures. Therefore, the quality of teaching with large student numbers is one of the top priorities of the Technische Universität Berlin. An university-wide study reform program aims to improve study conditions and to foster the quality of teaching and learning.

Therefore, a series of teaching projects focussing on digital teaching is currently funded at our university in the framework of a special project line. Digitalization not only drives Industry 4.0, but is also excessively integrated within educational processes. The new technological opportunities allow individuals to study more flexible, realise different multifaceted content for complex topics and to provide and get individual feedback on the learning process.

This paper provides information, progress and first results on different teaching projects, which are integrated within different courses at our university. This publication is based on research funded by the German Federal Ministry of Education and Research (BMBF) under the project number 01PL 17024.

1. Introduction

In this paper we present several projects of an initiative for innovation and improvement in teaching at the Technische Universität Berlin. This initiative is financed by the by the German Federal Ministry of Education and Research (BMBF) as part of the German Higher Education Pact 2020. The largest part of the initiative is called *tu wimi*^{plus}, consisting of 10 projects funded for 4 years from 2017 - 2020, focussing on improving the educational process in large courses in the beginning phases of the undergraduate studies by implementing novel tools and evaluating didactic methods. With these and other projects, innovation is brought specifically to courses and areas, where improved teaching methods are desired, for example to reduce the failure rates or lack of motivation of the students, in large courses and graduation programs with high drop out rates.

First, a selection of the teaching projects, their approaches and first results on these projects are presented. Afterwards, commonalities and differences are being discussed with an outlook on subsequent steps.

2. Targeted Inversion in the Online Project Laboratory in Chemistry and the project SynTUBio

One approach to implement new technologies into curricula is done by "flipping" of the distribution of homework and presence teaching in the classroom [1], [2]. The flipped classroom represents more interactive teaching, leaving more time for new forms of student centered learning like Research Based Learning (RBL) [2], [3], [4], [5]. The basic idea of flippedclassroom is not restricted to theoretical subjects, but it transforms the perception of instructive elements from the classroom to the preparation time at home. In such sense the time of the classroom presence is better used for real performance instead of perception of instruction. The implementation of instructional teaching videos into general higher educational teaching is understood as blended learning or online teaching [6]. According to Schultz et al. [7], flipped class chemistry students performed better and even had a favorable perception of this approach. Such positive effects were shown in a broad series of studies in very different subjects ([8], [9], [10]) and in many fields such as mathematics [11], [12] but also special lectures like synthetic biology or practical courses in physical chemistry and project laboratories [11], [13], [14]. However, there are also critical voices claiming that introducing digital teaching might lead to reduced students' attention or distract students from the difficult learning materials to digital tools with less impact on a successful competence development [15]. We believe, that this can be avoided by targeted inversion of selected classroom topics where a steady formative evaluation of digital teaching and subsequent adaptation improves the applied elements with focus on flipping just a part of a lecture or practical courses. This approach called targeted inversion can be used in lectures with arbitrary large student numbers when parts of the lecture, possibly highly repetitive topics, additional instructions or further examples are offered as additional content to the lecture [13]. However, it turned out that also small groups of students working in internships or on their own projects strongly profit from targeted inversion. In our practical courses of physical chemistry large advantages were gained from available online videos and online pretests for selected topics. Such online pretests and preparation videos were mandatory to start over with the experiments [13]. In the internships of physical chemistry such offered online pretests with selected video support improved the quality of the students protocols significantly and it was clearly visible that the students were more competent in conducting the experiments [13].

We therefore decided in 2013 to apply the approach of targeted inversion to the Online Project Laboratory in Chemistry (OPLChem) [14]. In the internships of physical and organic chemistry, the students were offered a series of teaching videos as supporting online materials. However, in the OPLChem they were additionally involved into the generation of online blogs and online videos as a form of documentation of their experiments. One idea of the targeted inversion is to extract the optimal and/or most advantageous approach from the concept of blended learning and to leave disadvantageous elements of online teaching behind [14], [16]. As the students of the OPLChem profit strongly from preparing a video documentation of their own experiments, it turned out that the implementation of video production is a more useful concept than the pure perception of online videos. Additionally, the students produce clips that introduce their projects with small "teasers" to students of the following classes. Such teasers are suitable to transfer the information of the experiments as their main aim is to support the idea of student centered projects rather than helping the students to understand such topics in detail. For such deep understanding of other groups' projects there is basically no need in the OPLChem as each student group has to conduct their own newly defined project but it turned out that there is a strong need for qualitative best practice examples and ideas at the beginning of the semester to help the students quickly define their own project topics [11], [14].

In the OPLChem the students conduct their own projects and plan their own experiments in the framework of RBL. The topics are often related to contemporary research topics in ecology, sustainability or social and intercultural debates and therefore of high societal interest. It was reported in literature that free-choose learning and research promotes environmentally sustainable attitudes and behaviour [14], [17], [18], [19]. In recent years about ⅔ of our students chose projects directly related to sustainability research such as the quantification of heavy metals in drinking water, in nutrition supplements, in food and soil; the production and decay of biodegradable plastics, electricity from bacteria, fuel cells, hydrogen from bacteria, photosynthesis research and alternatives for industrial fertilizers. The concept of the OPLChem to produce online-videos and publish blogs in the internet further motivates the students to decide for projects related to sustainability research by giving them the opportunity to present their results to the public. OPLChem starts with best practice examples introduced by students from former semesters (as part of their presentation) motivating the new students' research questions followed by the investigation period for studying existing literature and collecting information and the conception period combining ideas to an experimental concept, defining methods and considering the setup. Then the students conduct their research in the laboratory during the experimental period in groups of 2-4 participants. At the end of the course the students have to present a written protocol and produce either a video or a blog where the conducted experiment and the results are described. Usually the video and blog are hosted at YouTube® or Wordpress®, respectively, and therefore public. Their presentations are impulse talks for the next group of students. The OPLChem takes place every year and is now continuously offered in the framework of the orientation study program MINT*grün* of TU Berlin. The outcome of the students efforts can be found and directly viewed on a central Wordpress® platform where all student blogs and videos are linked (www.oplchem.wordpress.com).

In the currently running project "SynTUBio" started 2017 we now transfer the concept of targeted inversion by teaching videos, to producing more general videos covering a broader view ranging from basic teaching content (like mathematics) or applications in practical courses (mainly in physical chemistry, organic chemistry and synthetic biology) to research during the PhD or during laboratory work as a scientist who is employed in a research department of a company.The materials therefore give a broad view on background, motivation, applications and job perspectives which are related to certain topics in basic chemistry courses. We believe that such approaches highly relevant for orientation studies and especially the student beginners in all STEM courses to allow students not only to experience the different approaches of the different graduation programs, but also the reality they are facing during the whole program and after graduation. This enables them to judge early if such working conditions are compatible with their expectations and helps to conduct the right choices early in their studies.

3. The Computer System Simulator SysprogInteract

SysprogInteract describes a simulation framework aiming to improve the digital content for an undergraduate computer science course, computer system programming, at the Technische Universität Berlin. In the field of computer system programming, complex dependencies between hardware and software solutions exist, which are in focus of the study. Theoretical developed algorithms are applied in order to interact with hardware components. Even though, this topic is highly practical, as it covers the theoretical concepts of any modern machine like computers and smartphones, it is still difficult to provide easy access to any practical experience as the gap between current hardware solutions and basic implementation of operating system processes is too large for undergraduate students. Additionally, the number of students attending this course increases constantly, such that currently more than 800 students visit our course, we are not able to provide individual feedback to every person. Thus, we aim to create an interactive simulation framework (SysprogInteract), which can be easily integrated into the education process and fulfill the student's expectations on a modern, digitized education. In such sense SysprogInteract delivers the opportunity to involve a large student number into practical computer system programming as automated feedback is delivered in a standardized way.

Rieber [20] has shown, how animation can be beneficently integrated into the educational process, providing recommendations for several different disciplines and Lawrence et al. [21] showed the effectiveness of animating algorithms for teaching. In the field of system programming, there also exist work for animating different parts of an operating system, e.g. by Jones and Newman [22], Suranauwarat [23], Kotainy and Spinczyk [24], and Zareie and Najaf-Zadeh [25]. They all provide animations for the different computer system components, visualizing the algorithmic behaviour, but lack on providing the dynamic relationships between these components.

Within this project, we therefore develop an extensive simulation framework providing visualizations for key computer system parts (Processor Unit, Random Access Memory and Hard Disk Memory), with the possibility for enabling the chance to test several different algorithms. We use modern visualization frameworks like D3js, in order to provide aesthetic simulations, which motivate students to interact with the application and create modular code blocks for easy adaption in order to including further algorithms. Through continuous user studies, we iteratively develop the application and where able to show SysprogInteract provides good usability and motivates students.

SysprogInteract can be used within lectures in order to demonstrate complex algorithms, while giving the chance to pause the animation and providing navigation opportunities going single steps back in the animation. As the solution provides visualizations for interdependencies of system components, different chapters of the course can be visually connected and may give further motivation, why specific algorithms are selected for demonstration. Additionally, SysprogInteract provides the possibility to save and load configurations, such that tasks can be created and the results analyzed with the simulation. Such exercises can be used for tests or interactive sessions within small group exercises. As the tool is developed as web application, students use the simulate also from home for learning.

In future, we also want to integrate the possibility to edit algorithms by students themself, in order to provide more practical usage of simulation by creating or adapting teached algorithms. The developed solution is published as open source project (add link here) in order to give access to the simulation to any education facility. Furthermore, we produce videos in order to show the setup and usage of SysprogInteract.

4. E-Learning as a supplement for Theoretical Computer Science education

In basic courses on Theoretical Computer Science, there is often a high amount of frustration and failure rates are usually high as well. [26], [27] The heterogeneous groups of students in such courses can be supported using E-Learning solutions.

Our approach uses the learning management system Moodle to supplement courses on Theoretical Computer Science with E-Learning elements. These courses are a beginners' course on Formal Languages and Automata and a more advanced course on the modelling of Reactive Systems. These so-called learning units are created based on design recommendations of learning theories, mainly the Cognitive Load Theory by Sweller [28].

We chose four weeks of course content for each of the two courses and created explanatory material. The material is in the form of text as well as in the form of video. The students are able to switch between these presentation forms. Additionally, exercises were created to allow students to test their knowledge individually and get direct feedback on their answers. Students can not only choose the presentation form but use learning paths as well to choose if they want to see introductory examples on the next content part first or start with the explanation right away. If they perform very good on the exercises (75 percent of the points or more), the students can unlock bonus pages with open questions or ideas for the usage of additional tools like theorem provers in relation to the course content.

With the main question how the usage of these learning units affects learning motivation and the acquired competencies, the learning units are currently being evaluated using studies in a repeated measures design at several university locations, inter alia at the TU Berlin. The students of the courses are divided in balanced groups with one group using the learning unit for two weeks additionally to the course and the other group just using the course material. Questionnaires are used to determine if motivation and competencies change differently for these groups. After these two weeks the roles of the groups change and the procedure is repeated for the next two weeks with the corresponding learning unit. This quantitative evaluation is complemented by structured interviews, to find out more on the advantages and disadvantages of these units. Up to now, no significant advantage of using the learning unit can be shown, but the feedback of the students is highly positive.

An important advantage of this approach is, that it can be adapted for other university locations with similar courses on Theoretical Computer Science. Additionally, the approach can be adapted as well for other courses inside and outside the area of Theoretical Computer Science. Evaluation results for six studies in five different universities are currently analysed. The learning units are now already provided without restrictions in courses at the TU Berlin and the University Duisburg-Essen.

5. Didactic diversity to improve learning and teaching quality for Computing in Civil Engineering

Computers are essential tools for civil engineers. As a consequence, basic skills in computer science are necessary for each person working as a civil engineer. Most of the course programs in civil engineering in Germany offer lectures in this field. The difficulty in teaching is that computing is much more than a skill to be learned [29]; the application to civil engineering problems is an additional challenge. Teaching computing in architecture, engineering and construction (AEC) must focus on more aspects than the use of commercial tools [30]. With this in mind, it becomes crucial to teach students basic skills that help them to adopt problems and create their own solutions based on computer science technologies.

Own evaluations show that the acceptance of courses in applied computer science is relatively low as it is not seen by all as a necessary skill for a civil engineer. Based on this knowledge, existing courses have been scrutinized. The chair for Computing in Civil Engineering at the Technische Universität Berlin gives two compulsory undergraduate courses. 100 to 150 students participate in each of these courses. Both include homework assignments and one or two written examinations. The students must work on own implementations as part of the homework; and the students must know the theoretical background which is checked in written examinations. Goals of the redesign of the courses are improvements in the acceptance and a better understanding. For this purpose, several modifications took place. The basic idea was the introduction of didactic diversity addressing every student in a way that motivates him or her for contents of the courses. Four concepts were developed and are partially used in the two courses. The amount of concepts is consciously restricted to four not offering an unnecessary diversity.

The first concept includes homework assignments build on one another. Therefore, a useful program is stepwise implemented by each student to have a higher practical orientation. Students get the opportunity to create solutions for given problems and to improve them with the next homework. On the one hand this serves as a motivation and on the other hand, it deepens their understanding of the content of the courses. Individual feedback is given to support effectively and to create a better understanding for mistakes and how to avoid them.

The second concept is the flipped classroom. It has already been described in Section 2 for the Online Laboratory in Chemistry. As an introduction to programming a video and a few easy task were created that introduce the integrated development environment (IDE) eclipse and Java programming. The students are invited to try it at home and to ask questions the following week in open sessions offered for this purpose. The tutorials of the course base on the knowledge of the video so the students get the opportunity to do and retake the exercise whenever they like in a specific period.

The third concept are homework assignments that are developed as a direct preparation for the following tests. The processing of the homework reduces the preparation time that is needed for the respective test and combines the calculation made by hand with an implementation in Java.

The last concept contains audit questions from students for other students. As a part of their homework assignments they are invited to create own exam questions of the covered topic. This is a feedback for the lecturer as well, because excellent questions can only be created by a student who really comprehend the content or at least most parts of it. Sensible questions are revised and altered in order to expand the pool for possible questions for written examinations.

Through the last year, own evaluations were conducted, which prove that the presented concepts increase the acceptance and motivation of the treated subjects. A short evaluation in every weekly tutorial with not more than 20 students was made to get a better insight of the struggles of the students to the different topics. Only two questions were asked, one for the difficulty of the topic and the other to the pace of the tutorial. Lectures and exercises in the lecture room are evaluated once during the execution of a course. Results can be summarized as that the courses are still seen as difficult but also as manageable. The described concepts are integrated successively and current evaluations show that the acceptance of students towards computing increases.

6. Discussion and Outlook

The projects presented in this paper originate from quite different areas like Chemistry, Computer Science and Civil Engineering. Commonalities can be found here, although the course sizes and the reasons for the innovations are quite different, like the improved usage of classroom time, further motivation, engaging the students or the possibility to add practical elements. The approaches presented in Sections 2 and 5 improve usage of classroom time and student engagement by various didactic elements, e.g. variants of the flipped classroom model. The idea of these approaches can be transferred as a didactic model to many course situations where engagement should be enhanced. Especially, it turned out that the specific elements that are digitalized and the final tools used for should be strictly evaluated and adapted. In such sense the targeted inversion and concomitant establishment of digital teaching can be further improved to enhance quality and avoid its disadvantages. Implementation of augmented reality and simulations can help to further help for understanding complex setups or complex mathematics as in the practical courses of chemistry (Section 2). This also accounts for complex simulations as presented in Section 3.The approaches presented in Sections 3 and 4 both deal with large course sizes and use tools for their specific situation to improve teaching possibilities. These tools can be transferred to similar courses as well as the underlying didactic ideas. Through monthly meetings, all project partners share their progress, problems and discuss overlapping challenges to be tackled. The initiative enforces the transfer into further courses within the TU

Berlin, but also to other university, providing for some tools e.g. open access to code or further media.

Therefore, it is believed that Digital Teaching has the potential in significantly contributing to improved teaching and learning scenarios if it is done in such way that elements developed in the modules presented here for a long time period of several years with subsequent formative evaluations and adaption to match students demand are taken over into the regular curricula, disseminated and continuously monitored. Besides individual project related evaluation, the central controlling team collects reports in order to determine the overall impact of the initiative. So, the selective decision for specially designed digital elements is the key factor for improved teaching leaving behind negative impacts of digital teaching. We therefore recommend to incorporate continuous digital development into the curricula with specially qualified positions in such field instead of the recent approach of project based financing and random initiatives that arise on the engagement of single persons.

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