On Supplementing Theoretical Computer Science Courses using E-Learning

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ABSTRACT

Courses on Theoretical Computer Science often have to deal with a high amount of frustration and high failure rates. To find a possibility to counter this, interactive learning units for self-studying and self-testing using exercises were created in the learning management system Moodle. These learning units were offered as supplementary material in the winter term 2017/2018 and the summer term 2018 in courses at the german universities Technische Universität Berlin and RWTH Aachen. In this article, the studies, which evaluated the effects of this offer, are presented and their results are discussed. The results indicate that the learning units were helpful for the students concerning the course content as well as several motivational aspects.

CCS CONCEPTS

• Social and professional topics → Computing education; **• Theory of computation → Formal languages and automata theory**;

KEYWORDS

Theoretical Computer Science, Learning Management System, E-Learning, Blended Learning

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1 MOTIVATION AND CLASSIFICATION

Courses on Theoretical Computer Science often face high failure and dropout rates.

In 2016, out of the 20 courses with the highest attendance in the Bachelor of Computer Science program at the Technische Universität Berlin, the four courses with the lowest success rates all were obligatory courses on Theoretical Computer Science. The mean success rate for these courses was 48.3 percent compared to a mean of 69.85 percent for all 20 courses. [24]

Various studies and papers on the subject of teaching Theoretical Computer Science report on failure rates above average, high dropout rates and frustration (e.g. [13], [12], [10], [23]). However, with all its emphasis on modelling and basic Computer Science concepts, Theoretical Computer Science is a relevant part of Computer Science study programs, as can be seen from the recommendations for such programs by the german 'Gesellschaft für Informatik' [2] (which translates to German Informatics Society). Theoretical Computer Science is part of several of the outlined content areas in these recommendations. This allows for the conclusion that the teaching of Theoretical Computer Science needs to be improved. Students need a wider variety of exercises, facilitated and individual access to learning and the possibility to learn according to their own pace. As discussed by Gros and García-Peñalvo in [11], E-Learning is a possible and useful solution in such a case. The learning units, that were created for the studies presented in this paper, are used as a solution approach. This approach allows us to further support the heterogeneous group of Computer Science students. Based on this idea of individual support, the learning units are designed and used as a supplement in already existing courses. This allows for a higher level of diversity in teaching, to help students independent of their learning pace and preferences. Our basic research question is how a typical course on Theoretical Computer Science and the same course supplemented with E-Learning material differ concerning learning motivation and the increase of competencies. E-Learning units of a clearly defined size - one moodle course - will be referred to as learning units in this paper. The planned setting of the studies, here described in Section 4, was already discussed in [27], yet without results and restricted to the study at the Technische Universität Berlin.

Approaches to improve Theoretical Computer Science education for the learners have been carried out in multiple locations in the past. One example was the use of a theorem prover in the introductory study phase [4], the supplement of such courses using screencasts [19], the redesign of a course from a social-constructivist point of view [13], focussing on didactic strategies like contextualisation [5] or the use of tools like JFLAP to create and transform automata as for example in [22]. Unfortunately there can be found substantially more actual implementations in courses than scientific evaluations of the approaches like the one discussed in this paper.

In the following, first the learning theoretical background is discussed in Section 2, then the concept of the learning units and the main didactic decisions in creating them are discussed in Section 3. Subsequently, the structure of the study is presented in Section 4 and the results so far are being reflected in Section 5.

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2 THEORETICAL BACKGROUND

The learning units are prepared using basic principles of learning theory. Therefore the design is based on recommendations derived from the *Cognitive Load Theory (CLT)*, the *Cognitive Theory of Multimedia Learning (CTML)* and the *Cognitive-Affective Theory of Learning with Media (CATLM)* in combination with the theory of learning styles by Felder and Silverman.

2.1 Cognitive Theories

According to the CLT, content is perceived in the form of so-called schemas in the strongly limited working memory. Content is learned when it has been processed in the basically unlimited long-term memory and connected to existing knowledge. Only a small amount of content can be processed simultaneously. For learning, Sweller distinguishes intrinisic cognitive load (how strongly are the elements to be learned interconnected and how 'hard' is it to learn them) and extrinsic cognitive load (how the content is presented). [25] Later, in [26] the germane cognitive load (how intensively the learner has to engage with the content) was added to the theory.

Mayer builds upon this with his CTML. He assumes learning material is received via two channels (visual and auditory). Afterwards, relevant information has to be selected and actively processed to verbal or pictorial representations. The learner combines these representations actively with existing knowledge. [16]

Moreno extended these theories with the CATLM by other factors that can influence learning. The main factors that influence learning according to the theory are motivational factors, metacognitive factors (e.g. learning strategies) and typical characteristics of the learner like his knowledge level and his abilities. [18]

2.2 Learning Styles

The term learning styles refers to cognitive preferences of the learner in the learning process. This differs from the so-called learning types according to Vester, where different channels of perception allow for differences in learning possibilities. [15]

The theory of learning styles by Felder and Silverman was first published in [7] and later made available online in an extended version [8]. It contains five dimensions, each ranging between two extremes, e.g. visual and verbal learners. The learning units presented in this paper were created in a way to contain elements of different learning styles that can be chosen by the learner. Thus the system gives more possibilities to learners preferring different styles than classical learning material. A possible extension could be adaptivity to the current preferences with the possibility to actively change or clear these preferences. Another extension could be tailoring the learning units explicitly to certain learning styles to allow students to choose between these styles. According to the theory, learners do not have a specific learning style, but tendencies to one or the other of the extremes in each dimension. These tendencies might, however, change on short-term as well as on long-term. The interaction between learning styles and the possibilities of their implementation in Moodle have already been discussed in [28].

The crucial dimensions we considered are: (1) Sensors are oriented to facts and the repetition of routines whereas intuitors prefer innovation and dislike repetition. Therefore the learning units contain many exercises, but it is possible to skip them. It is also possible to start with the exercises and to address the content later. (2) Visual learners learn best what they see, e.g. pictures and graphs. Verbal learners prefer written or spoken words. Both are adressed with the possibility to choose between learning content in textual form or with videos. The latter contain more graphical representations and the identical text in spoken form. (3) Sequential learners prefer content in linear order, like it is in typical classroom situations, whereas global learners prefer content in self-chosen order. These preferences are adressed with the content being presented in a suggested order but the order of the actual learning process can be chosen individually using the navigation menu.

3 CONCEPT AND DIDACTICAL DECISIONS

This section gives an overview of the content of the learning units and the competencies they try to convey. Afterwards the concept of the learning units is presented followed by the didactical decisions leading to this concept. The section ends with information about related research in this area.

3.1 Content and Competencies

The aim of the learning units is to increase motivation and the acquired competencies of the students. Two quite different courses on Theoretical Computer Science topics were chosen to show that the concept can be applied for different target groups and in several areas. Both courses are taught at several universities. The first course is on formal languages and automata (and therefore from now on called *FLAT*) and is obligatory in many universities in the Bachelor of Computer Science study program, including the Technische Universität Berlin. The second course is on reactive systems (from now on called *ReSy*), mainly on the modelling of processes and how fixed points can be used to compute properties of such models. This course is taught at the Technische Universität Berlin as well as the RWTH Aachen. *ReSyTUB* or *ReSyRWTH* will be used as abbreviations if one particular course is being referred to.

Comparing the courses at the study locations and similar courses at other universities resulted in the competencies that should be acquired in the learning units. The content presentation and the type of exercises in the learning units are oriented to these competencies. There is, however, no competence model for this area until now. It is for this reason that the term competency will be used only cautiously in this article.

For each course, two content-specific learning units were crafted. These cover for the first learning unit of *FLAT (lu1)* deterministic and nondeterministic finite automata and how these automata accept regular languages. The powerset construction is used to show how a nondeterministic finite automaton can be transformed to a deterministic one, which is important to prove that both accept the same languages. Additionally, the pumping lemma is covered to prove that a given language is not regular. For the second learning unit *(lu2)* they cover the minimisation of automata using the table-filling algorithm and the Myhill-Nerode-relation and how the latter can be used to show if a language is regular or not regular based on the question if there is a finite or an infinite number of equivalence classes. The construction of the equivalence class automaton for the finite case and the proof that it is not a regular language for the infinite case are shown. Further pushdown automata are covered and the languages they accept for the deterministic and nondeterministic case. The competencies that should be acquired in these two learning units are:

- Using fundamental tools of computer science
- Applying algorithms and proof methods
- Using formal languages and automata confidently
- Understanding properties of formal languages and automata

For *ReSy* the first learning unit *(lu3)* covers trace equivalence and strong bisimulation to compare processes. Proofs are covered to show that one LTS is strongly bisimilar to another one. As a further abstraction level, weak bisimulation is introduced to compare processes in spite of their internal steps with similar proofs. The second learning unit *(lu4)* covers general fixed-point theory, lattices, the computation of fixed-points and the special case for finite lattices. Finally bisimulation as a fixed point is covered using a function to compute the largest fixed point, which is also the largest bisimulation. The competencies that should be acquired in these two learning units are:

- Understanding the theoretical foundations of concurrent systems
- Modeling and comparison of concurrent systems
- Understanding of the semantic concepts
- Applying theoretical concepts to solve formal tasks

3.2 Concept

Each learning unit is created as a Moodle course. A unit consists of blocks like the one in Figure 1, each covering one part of the topic of this unit. The headline and the short introductional text explain the contents of this block. This is followed by the link to a lesson (with the three linked blue boxes), that contains the actual content and questions to deepen the understanding of this content. Additionally there is another link opening a quiz with more complex questions on the content (with a red checkmark), for the learner to further test his knowledge and deepen his understanding. Below, there is the link to the bonus page (still greyed out) with the stimulus in which part of the block the hurdle has yet to be reached to be able to see the page. This hurdle will be further explained in Section 3.3.

Figure 2 shows the characteristic first page of a lesson (after one has clicked on a link with the three linked blue boxes as in Figure 1). Below the headline, two buttons are visible. The left one leads to the same content as shown on the page but presented as a video. The content of the video is identical to the textual form with the text read completely as audio track and visualisation of formulas and connections (often more graphical than in the pure textual form) in the video. The right button opens the graph of this lesson, showing the different possible learning paths. These learning paths will be explained in further detail in Section 3.3. The following text on the page gives an introduction into the topics of the lesson with first explanations. Below, the learner can choose where to go next on the learning path using the buttons. The left buttons leads to introductory exercises for the following topic, the right one to the explanation for the upcoming topic.

In the upper part of Figure 4, a typical multiple-choice question can be seen where the learner can choose his answer. The lower part presents the chosen answer combined with feedback why the answer was incorrect. Feedback is also given for correct answers. The buttons below allow the learner to either repeat the question (for example to improve the score to unlock the bonus page of this block) or to continue. The latter is possible regardless of the fact if the answer was correct or incorrect. Repeating questions later is also possible.

3.3 Didactical Decisions

The learning units are didactically based on the idea, that students have the possibility to get direct feedback with explanations why their answer was incorrect or correct. This gives them an indication of their current progress. Additionally they can interact with the system using the navigation and the multiple-choice questions. This is possible to allow for a more individualized learning experience and to help students with various learning progresses. A learning unit comprises inter alia of several so-called lessons, which is a standard module of the Moodle system. Learners in our lessons have to a limited degree the possibility to choose between learning paths inside of a lesson and take individual decisions. The term learning paths refers here to the possibility to decide at certain points which element the learner wants to see and interact with next. The paths, however, are outlined very clearly and are additionally explained using graphs, like the one in Figure 3, showing the connections between the different elements. This is done on the one hand not to overstrain the students with too many possibilities to choose from, but on the other hand present them with real alternatives in these learning paths. The students can, for example, choose if they want to work on introductory exercises for a new topic or go straight to the explanation. The reduction of possible choices in the learning paths goes together with the limited processing capacities according to the CLT [25]. Based on the idea of mastery learning [3] a high rate of correct answers in the learning unit (more than 75 percent correct answers) unlocks bonus pages. These pages ought to help in motivating the students. The bonus pages contain additional open questions on the content to think about or suggestions for interesting tools and exercises with these tools, based on the content. The exercises in the learning units can be answered repeatedly. Students can test themselves and their progress and are able to answer them at different times, for example during the semester as well as in preparation for the final exam. The hurdle for the bonus pages therefore does not have to be reached in the first attempt to prevent frustration on this matter.

3.4 Related Work

There have already been studies carried out to improve Theoretical Computer Science education. Armoni [1] and Pillay [20] conducted two studies on the difficulties students have in courses on Theoretical Computer Science. In both studies, the results are mainly that difficulties arise in the area problem solving. Therefore we included problem solving to a certain degree into the learning units, for

Figure 1: A block of the learning unit for course A

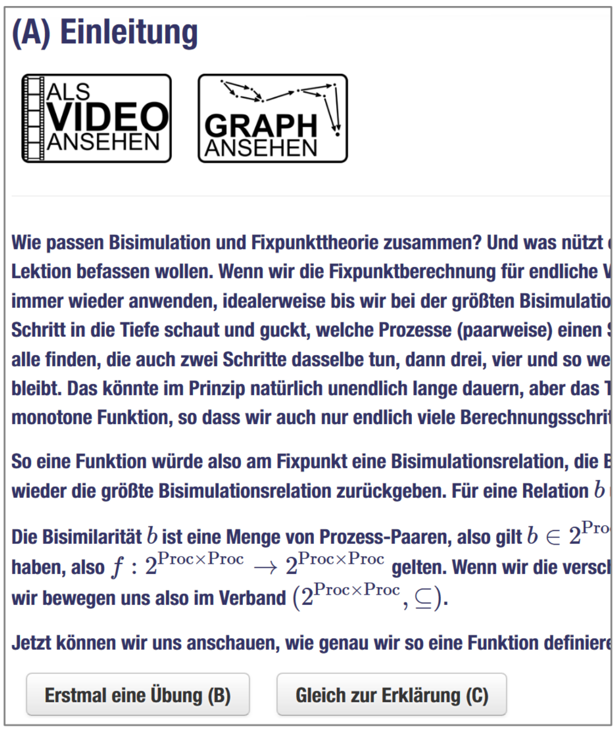

Figure 2: Introductory page for a lesson with buttons for watching the video instead of the text, viewing the graph structure of this lesson and on the bottom buttons for the next steps in the learning path

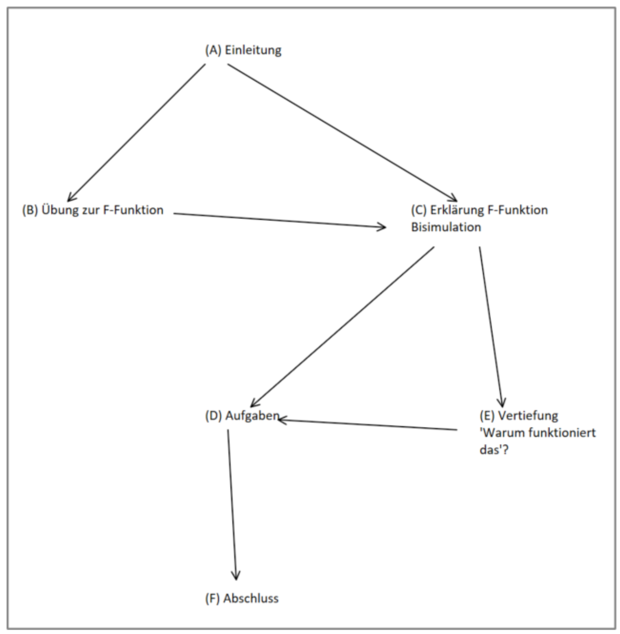

Figure 3: Graph structure of a lesson

example in the proofs using the pumping lemma or in minimizing automata. Pillay even suggests the use of direct feedback, which is part of our system, or the usage of Intelligent Tutoring Systems. These systems have many properties in common with the system described in this paper, like exercises with immediate feedback, individualized learning and interactivity. Knobelsdorf and Frede [12] found in their study a lack of work proficiency and familiarity with the necessary methods to solve exercises. A self-regulated approach combined with individual feedback for exercises like ours might help in developing such skills, if the students can be interested in using it.

4 EVALUATION

This section presents the setting and the general structure of our studies. Afterwards the surveys are presented in more detail followed by details on participation concerning the study.

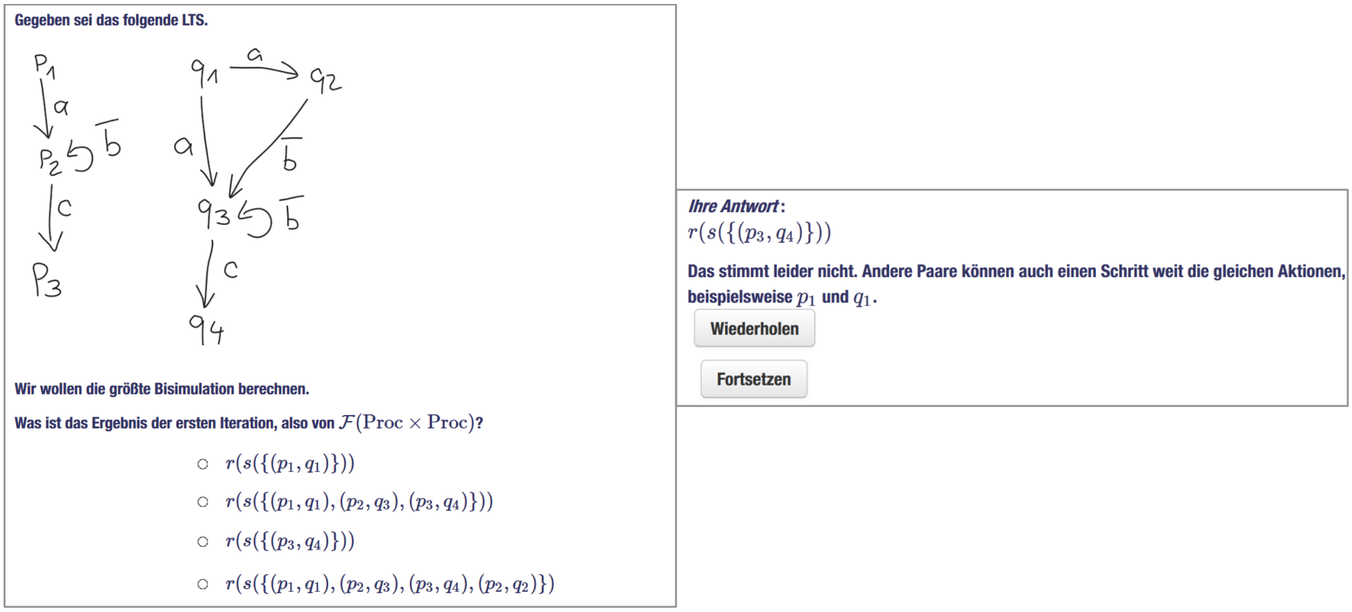

Figure 4: Multiple-choice exercise (left) with feedback for an incorrect answer (right)

4.1 Setting

The studies were conducted in the winter semester 2017/2018 at the Technische Universität Berlin (*FLAT*) and the RWTH Aachen (*ReSyRWTH*) and one study in the summer semester 2018 at the Technische Universität Berlin (*ReSyTUB*). FLAT is obligatory at the Technische Universität Berlin. The course is usually attended in the first semester. Occassionally students of other study programs attend the course. Homework is handed in every four weeks in groups of three to four students. These homeworks together with a mid-term e-assessment and a classic pen and paper exam at the end of term are part of the student's grade. Students get six ECTS credits for the course that comprises lectures and tutorials in smaller groups. The course *ReSyTUB* is one out of three advanced courses on Theoretical Computer Science in the Bachelor of Computer Science study program at the Technische Universität Berlin. Grading is based on an oral exam. Students get six ECTS credits and the course also comprises lectures and tutorials. The course *ReSyRWTH* is part of one of the four compulsory areas in the Master of Computer Science at the RWTH Aachen. Grading is based on an oral exam. Students get six ECTS credits and the course also comprises lectures and tutorials.

4.2 Structure

The structure in a repeated measures design was basically identical and can be seen in Figure 5.

At first, the participants were asked to answer a preliminary survey, here called Survey 1. Afterwards, they were divided into two groups A and B based on their answers. This group division will be further explained later in this section. Now the students in group A had access to the first learning unit for a period of two weeks. Apart from that, both groups attended the course just as usual. After these two weeks another survey was conducted with both groups (Survey 2). Afterwards group B had access to the second learning unit for the same period of time, covering the course content of these two weeks. Afterwards both groups were again asked to fill out a survey (Survey 3).

All three studies are designed as supplement to the courses. The course itself is not modified in any other way. Participation in the study was optional and was promoted in the lecture, the websites used for the course and in the *FLAT* course additionally on the sheets handed out in the tutorial. Among all participants, Amazon vouchers were raffled. The experience of low participation gained during the study in *ReSyRWTH* led to the additional offer for the participants in the *FLAT* and *ReSyTUB* courses to get access to both learning units after the end of the study to prepare for the final exam at the end of the semester. Making participation obligatory for participants was not an option due to exam regulations at the Universities.

4.3 Surveys

Survey 1 consisted of a self-constructed questionnaire that was built based on existing questionnaires (inter alia the MSLQ [6]), measuring the affinity to learning management systems and the abilities for self-regulated learning. The motivation for learning the content was measured by showing the students four questions on the content of the four course weeks the study took place in. The students were asked not to answer these questions right away, but to think about how they would solve them. Afterwards they were asked to fill out the QCM [21] questionnaire, measuring the current learning motivation in such situations. Afterwards the students once again were shown the content questions and this time they were asked to answer them. More questions followed on preliminary knowledge concerning the content of the learning units. This part of the questionnaire was concluded by questions on power sets.

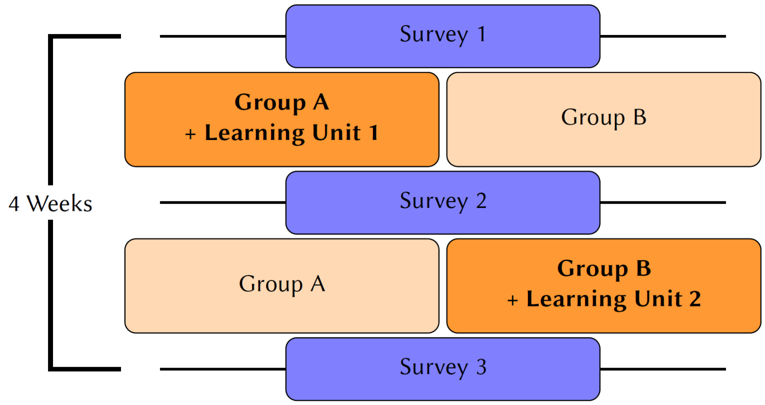

Figure 5: Structure of the studies

These can be seen as basic knowledge that is important for both courses. These questions were useful to better be able to assess the knowledge level of the students. The last part of the questionnaire consisted of the Index of Learning Styles (ILS) with questions on learning styles [9], sociodemographic questions and questions to form a code for pseudonimization.

In Survey 2, the current learning motivation was measured again using similar questions as in Survey 1 again in combination with the QCM questionnaire. Afterwards students were asked to answer questions on the course content of the past two weeks and questions on preliminary knowledge for the following two weeks. For those students that had already had access to the learning unit, the UEQ [14] was used in combination with open questions to find out more about the usability and the usage of the system.

Survey 3 was structured similarly to Survey 2 but without questions on preliminary knowledge.

With the aim to create conditions as similar as possible for both groups A and B, the students that filled out Survey 1 were seperated into two groups as evenly as possible. First we tried to balance out genders to avoid gender differences. With lower priority for each further step, the groups were balanced out on their study program (e.g. Bachelor of Computer Science, Bachelor of Mathematics or the faculty's orientation program), the results on their preliminary and basic knowledge, their interest in learning in groups, their interest in self-regulated learning and their learning motivation. As a result of the low participation rate the participants of the study were asked for additional short interviews after the study had finished, where they were questioned on strengths and weaknesses of the learning unit and on their usage of the unit. In the *FLAT* course three students participated in these interviews and five students in the *ReSyRWTH* course. Further interviews in the *ReSyTUB* course are currently being evaluated.

4.4 Participation

An obstacle encountered in conducting the studies was the low participation rate. The course *ReSyRWTH* itself started with about 20 students, only three of which fully participated in the study. The Surveys 1 and 2 were filled out by four students each. The course *FLAT* started with about 600 students. Of these, 37 participated fully in the study. The course *ReSyTUB* started with about 100 students, 22 of which participated fully. It is therefore likely that these students do not represent the average course participant, but already have been particularly engaged. Initially there was another survey planned in all courses after the final course exams to get more information about the grade range of the students. This study took place only at the *FLAT* course due to the low number of participants in *ReSyRWTH* and due to the fact that the exams in *ReSyTUB* are not yet finished.

5 RESULTS AND REFLECTION

To give a clearer overview of the studies, we restrict the presented statistical results to the larger samples (those at the Technische Universität Berlin) and present the comparison of the groups for the *FLAT* and *ReSyTUB* courses concerning motivation and knowledge. We only count students that fully participated in the study. Additionally first results of the interviews for *FLAT* and *ReSyRWTH* are discussed. It is important to note that due to the low participation rate the results of the study are neither representative for the whole course nor for example for the population of Computer Science students.

The means of the QCM scales and the mean of the percentages achieved on the content questions for the *FLAT* course are shown in Table 1, those for the *ReSyTUB* course are shown in Table 2. For the Surveys 2 and 3, the values of the group that had had access to the learning unit in the past two weeks are emphasized. One difficulty in the interpretation is, that the scales of the QCM are directed differently. A large number as result for probability of success is good, while a large number as result for anxiety is not. While participating in such a course the probability of success should ideally increase while the anxiety should decrease.

In the following, first the statistical results of the QCM questionnaire and the knowledge tests are being discussed with possible interpretations, afterwards the interviews will be discussed and interpreted.

5.1 Survey Results

First insight into the data can be given by descriptive statistics. In the *FLAT* course the anxiety for both groups decreased during the

Table 1: Means and standard deviations (in brackets) of motivation and knowledge for each group for the *FLAT* study. Additionally the results of the t-tests for independent samples to compare the groups.

Survey Number	Scale	Group A (n=20)	Group B (n=17)	T	df	Sig
1	Anxiety (QCM)	3.79 (1.36)	3.08 (1.3)	1.598	35	0.119
1	Probability of success (QCM)	3.76 (0.77)	3.57 (0.557)	0.837	35	0.4
1	Interest (QCM)	4.27 (1.34)	4.29 (1.26)	-0.56	35	0.956
1	Challenge (QCM)	4.68 (1.1)	5.14 (0.80)	-1.4	35	0.163
1	Basic knowledge	0.55 (0.3035)	0.6 (0.2345)	-0.553	35	0.58
2	Anxiety (QCM)	**2.9 (1.24)**	2.7 (1.66)	0.356	35	0.724
2	Probability of success (QCM)	**3.76 (0.43)**	3.47 (0.49)	1.906	35	0.065
2	Interest (QCM)	**4.51 (1.1)**	4.8 (1.09)	-0.895	35	0.37
2	Challenge (QCM)	**4.56 (1.08)**	4.55 (1.01)	0.011	35	0.992
2	Knowledge learning unit 1	**0.783 (0.203)**	0.764 (0.195)	0.283	35	0.779
3	Anxiety (QCM)	2.67 (1.29)	**2.68 (1.4)**	-0.028	35	0.978
3	Probability of success (QCM)	3.6 (0.56)	**3.38 (0.406)**	1.324	35	0.194
3	Interest (QCM)	4.36 (1.02)	**4.32 (0.99)**	0.092	35	0.928
3	Challenge (QCM)	4.36 (0.95)	**4.55 (0.21)**	-0.505	35	0.61
3	Knowledge learning unit 2	0.662 (0.253)	**0.757 (0.17)**	-1.303	35	0.201

Table 2: Means and standard deviations (in brackets) of motivation and knowledge for each group for the *ReSy* study at the Technische Universität Berlin. Additionally the results of the t-tests for independent samples to compare the groups.

Survey number	Scale	Group A (n=9)	Group B (n=13)	T	df	Sig
1	Anxiety (QCM)	4.09 (0.85)	3.06 (1.34)	2.03	20	0.056
1	Probability of success (QCM)	3.86 (0.57)	3.88 (0.69)	-0.08	20	0.934
1	Interest (QCM)	4.22 (1.24)	4.23 (1.38)	-0.02	20	0.988
1	Challenge (QCM)	4.67 (1.3)	4.23 (0.9)	0.93	20	0.362
1	Basic knowledge	0.58 (0.27)	0.57 (0.3)	0.68	20	0.947
2	Anxiety (QCM)	**3.84 (1.3)**	2.85 (1.8)	1.43	20	0.168
2	Probability of success (QCM)	**3.94 (0.41)**	3.79 (0.32)	1	20	0.328
2	Interest (QCM)	**4.02 (1.08)**	4.03 (1.2)	-0.02	20	0.987
2	Challenge (QCM)	**4.61 (0.74)**	3.94 (1.02)	1.68	20	0.109
2	Knowledge learning unit 1	**0.63 (0.26)**	0.6 (0.28)	0.23	20	0.82
3	Anxiety (QCM)	3.69 (1.35)	**3.06 (1.9)**	1.47	20	0.405
3	Probability of success (QCM)	3.67 (0.43)	**3.77 (0.77)**	-0.36	20	0.723
3	Interest (QCM)	4.2 (1.52)	**4.14 (1.13)**	0.11	20	0.914
3	Challenge (QCM)	4.78 (0.79)	**4.15 (1.08)**	1.47	20	0.157
3	Knowledge learning unit 2	0.64 (0.17)	**0.72 (0.17)**	-1.1	20	0.302

study. The anxiety in the *ReSyTUB* decreased slightly in group A and stayed almost the same in group B. Also the difference between both groups decreased for *FLAT* as well as for *ReSyTUB* which leads to the hypothesis that the anxiety of the students was not strongly influenced by the usage of the learning unit. A possible explanation is here that the main influence on anxiety is the general comfort working with the content. Students felt more comfortable with the content in *FLAT* over time so the anxiety decreased, but students in the more challenging course *ReSyTUB* stayed at a similar level of anxiety due to the content. Further inquiries are necessary to test this hypothesis. The groups were initially balanced out but as several students did not participate fully in the study, the initial value of anxiety between the remaining participants differs in both cases quite a lot. This could probably be avoided by stronger incentives to participate in the study like bonus points.

In both studies the probability of success seems to be improved by the learning units. For each group that had the opportunity to use the learning unit the probability of success decreased less or increased more. The usage of the learning unit seems to improve the probability of success of the learners.

As with anxiety, the interest seems not to be influenced strongly by the learning units. Groups in both studies start with similar values which change over time (in *FLAT* the values increasd first and decreased afterwards, in *ReSyTUB* the values descreased first and increased afterwards), but the changes are similar for both groups respectively. Possibilities for the interpretation of these values for *FLAT* were sought out together with the Professor teaching the course, students and a group of PhD students of didactics. Possible reasons are the imminent final exam or differences in the perception of the difficulty of the content.

The challenge in both studies decreased less or increased stronger for the groups that had access to the learning unit for the past two weeks. This leads us to the hypothesis that the students that had a more intensive look at the content perceive it to be more challenging. Potentially these learners have a more realistic estimate of the difficulty of the content. Further inquiries are necessary to test these hypotheses.

The results for the knowledge questions are for each case in both studies better for the students that had access to the learning unit for the past two weeks. This leads us to the hypothesis that the knowledge of the students was increased by the learning units.

To find significant differences between the groups, t-tests for independent samples were used. The results can be seen in Tables 1 and 2. As changes are possible in both directions, two-sided t-tests were used. No significant differences were found between the groups for the significance level of 0.05. Solely the difference in the probability of success in Survey 2 for *FLAT* is close to significant (and significant for a one-sided test) and has, in contrast to group B, not decreased in group A that had had access to the learning unit the two prior weeks. Most effect sizes are small, few medium effect sizes were found.

5.2 Interview Results

As a result of the low participation rates and to get further information about strengths and weaknesses of the learning unit and the motivation to participate in the study, structured individual interviews were carried out. The moodle platform was used to ask students to participate in the interviews by forum posts and individual messages. These interviews were transcribed and the answers analysed using the qualitative content analysis according to Mayring [17]. A total of eight students agreed to be interviewed for the *FLAT* course and the *ReSyRWTH* course. The interviews for *ReSyTUB* are still being carried out. All of these interviewees were students in the Bachelor of Computer Science program at the Technische Universität Berlin or the Master of Computer Science program at the RWTH Aachen, respectively. Seven of these students were male.

Of the eight interviewees seven stated as the main motivation for their participation the additional learning material. All participants stated that the learning units had helped them in understanding the content. Half of the interviewees emphasized as an advantage of the learning unit explicitly that content was available in the form of text and video. The stated disadvantages contained for example once, that the videos were contentwise identically to the text. As the same detail was mentioned as an advantage of the platform several times there seems to be no urgent need to change this, but videos with a different focus would be possible. One approach is to keep the videos identical to the text but additionally link to existing videos on the content or similar content with another main focus, as far as such videos exist. Another mentioned disadvantage was, that the amount of material for each topic was about the same whereas the student would have preferred more content on some topics than others. For further versions of the learning units surveys could be used to find out which content areas need further examples or explanations. One student was unsatisfied with the usability. This could possibly be dealt with by the use of a better introduction into the usability, for example by the use of a clickable tutorial or a video tutorial. If such approaches do not help and usability is a frequent issue, changes could be made to the lesson module of Moodle. Concerning disadvantages, no homogeneous picture is presented by the answers.

Concerning the low participation rate of the study, similarly there is no homogeneous picture presented by the answers. Several reasons were stated, the most frequent answers were tight deadlines or lack of organizational skills of the students. These problems could be addressed by changes in the study design to allow access to the learning units for a longer period of time and the use of more extensive interviews and tests. If individual solutions for homework is possible (instead of group homework) the students could be asked to fill out a table how much they used the units in preparation and this information combined with the homework results could be evaluated anonymized. Many more approaches to keep the organizational part of the study easier for the students are possible, an alternative approach could be to make participation mandatory to pass the course. The latter, however, is often not possible due to the Universities' examination regulations and might lead to a strong bias in the results.

According to a common argument, support like the one presented in this paper is mostly used by students that would not actually need such support. For a better view on this issue we used the outcome of the end of term exam in *FLAT* to set up five grade ranges. These ranges are used in a way that students could be asked for their grade in a questionnaire without identifying themselves by their grade. A total of 50 points could be reached in the exam and the ranges are:

- 50-41 (A)
- 40-31 (B)
- 30-21 (C)
- 20-11 (D)
- 10-0 (E)

The participants of the study had the possibility to use both learning units from the end of the study until the exam (about two weeks). After receiving their grades the students were asked to fill out a follow-up questionnaire (omitted from Figure 5) were they were asked for their opinions on the units and additionally for their grade range. Table 3 shows the comparison of the distributions of the ranges of the 438 students that received a grade in the exam and the 25 students that filled out the questionnaire of the 30 students that had used the learning units to prepare for the exam according to the platform logs. The expected better grade ranges in the distribution can be found in the table. The grade ranges D and E (both below the 25th percentile in the course ranges) are not part of the stated ranges. The 75th percentile is on a higher grade range for the post-questionnaire ranges, as is the 25th percentile. Interestingly, the median is the same in the course ranges as well as in the post-questionnaire ranges. As the learning units covered only a

Table 3: Distribution of grade ranges in the end of term exam

	Course Ranges	Post-Questionnaire Ranges
Minimum	E	C
25th percentile	C	B
Median	B	B
75th percentile	B	A
Maximum	A	A
n	438	25

part of the course material tested in the exam, a significant improvement of the course ranges due to the learning units can only be assumed. Even though the students' answers to the questionnaire suggest, that that the students using the units had a tendency to a better grade range than the overall participants of the course, one must not forget, that grade ranges B and C still can benefit from support. These students might even lower the threshold for lower-performing students to use such supplementary material.

6 CONCLUSION AND OUTLOOK

The approach presented in this paper is intended to demonstrate possibilities in Theoretical Computer Science education to improve the support of heterogeneous student groups. Overall the results of the surveys and the interviews indicate that the approach is helpful. The studies give an interesting insight into the effects of supplementing a course with such a learning unit. Interestingly, the probability of success and the challenge seem to be influenced by the learning units, as is the knowledge of the learners. The anxiety and interest of the learners seem to be independent of this usage. Therefore the course supplemented with the material seems to differ concerning learning motivation and the increase of competencies from the course without the material, but not in every studied aspect of motivation. Additional studies with the same learning units in similar courses are intended to give further insight into this matter.

An advantage of this approach is the direct feedback on questions without impact on the students' grades. This feedback allows the students to find out independently if they have understood the content properly. Additionally they have the possibility to learn with the material independent of time and place. This allows for more flexibility, especially for students that have to work in addition to studying, raise children or have to care for their relatives. A possible disadvantage is, that students might not notice the supplementary character of the approach and use solely the learning units to prepare for the final exam. To avoid this situation it was communicated clearly that the learning units are not meant to be the single source for exam preparation. Not every possible type of questions (e.g. complex questions on proofs) is easily represented in such learning units, therefore not every aspect is represented in a convenient way. Solutions for such types of questions could in future approaches for example be uploaded and corrected manually, leading to a deeper involvement of the lecturer, which might be preferable.

The system presented in this paper can be used independently of the university's location and is therefore applicable for similar courses at other universities. Currently additional studies are being conducted at the Universität Salzburg and the Universität Duisburg-Essen to find out more about the effect of these learning units on motivation and acquired competencies. This clearly structured approach is easily generalizable and can be adapted to other topics and courses, especially as the Open Source platform Moodle is used for the creation of the units. Further material to especially support top-performing students could be integrated more differentiated in the future as with the current bonus pages to strengthen interest beyond the given course requirements.

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