Conception and Evaluation of E-Learning Units Regarding Motivation and Acquired Competencies for Theoretical Computer Science at University Level

Studies on the Topics of Automata Theory, Bisimulation and Fixed Point Theory

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This dissertation is dedicated to my wife and my kids.

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Abstract

Theoretical computer science is an essential part of computer science study programmes. Many articles from different countries can be found, which are concerned with the high levels of frustration amongst students, motivational problems, and high failure rates in courses on theoretical computer science. There are even indications that theoretical computer science is one of the reasons for the high dropout rates of computer science study programmes.

This dissertation presents a design-based research approach, aiming to improve the learning in university courses on theoretical computer science. For this approach, the author created interactive Learning Units in the learning management system Moodle. As theoretical basis, the cognitive load theory, the cognitive theory of multimedia learning and the cognitive-affective theory of learning with media as well as the Felder-Silverman model of learning styles were analyzed. All these theories were used to derive design recommendations for the Learning Units. Furthermore, existing approaches concerning e-learning in the area of theoretical computer science and meta-analyses on e-learning and blended learning in general were taken into account.

The created Learning Units use text and video as presentation forms and exercises on the content. Students can follow different learning paths on the content. On these paths, they can choose whether they want to be presented with simple examples introducing a new subject before its actual explanation. Another possible choice at several points is to follow a further extension on the content of the explanation if they are more deeply interested.

These Learning Units were intended for self-studying and self-testing using exercises. One pair of Learning Units were created for a course on formal languages and automata, typically attended at the beginning of the study programme, and another pair for a more advanced course on reactive systems. In both cases, the Learning Units were intended as a supplement to be used with otherwise unchanged university courses. Additionally, an evaluation instrument was created for these Learning Units, concentrating on student

motivation and competencies. The Learning Units were evaluated in six studies at RWTH Aachen University, Technische Universität Berlin, Universität Duisburg-Essen, Universität Potsdam and Universität Salzburg. Even though participation levels were low in the studies, the Learning Units were seen as helpful by many participants, and the overall results on competencies indicate positive tendencies. Overall, the results on motivation were ambiguous, but suggest possibilities for further research.

After these studies were finished, the created Learning Units were opened for public use. Additionally, they were made available for students in two courses at Universität Duisburg-Essen and Technische Universität Berlin in the summer term 2019. These two approaches were taken to ensure the sustainability of this work. Additionally, the dissertation discusses the possibilities for reusability of the approach for further Learning Units, not only for theoretical computer science but for different areas as well.

Zusammenfassung

Die Theoretische Informatik stellt einen wesentlichen Bestandteil von Informatik-Studiengängen dar. In zahlreichen Artikeln aus unterschiedlichen Ländern finden sich Berichte über hohe Frustration der Studierenden, Motivationsprobleme und hohe Durchfallquoten rund um Module der Theoretischen Informatik. Es gibt sogar Hinweise darauf, dass die Theoretische Informatik einen der Gründe für die hohen Durchfallquoten der Informatik-Studiengänge darstellt.

Diese Dissertation stellt einen Ansatz im Sinne des Design-Based Research vor, der zum Ziel hat, das Lernen der Theoretischen Informatik in Kursen an Universitäten zu verbessen. Dafür wurden durch den Autor im Lernmanagementsystem Moodle theoriegeleitet interaktive Lerneinheiten erstellt. Das theoretische Fundament bestand dabei aus einer Analyse der Cognitive Load Theory, der Cognitive Theory of Multimedia Learning und der Cognitive-Affective Theory of Learning with Media. Zusätzlich wurde das Modell der Lernstile nach Felder und Silverman mit einbezogen. Aus all diesen Theorien wurden Designempfehlungen abgeleitet. Zusätzlich wurden für das Design sowohl bereits existierende Ansätze betrachtet, die E-Learning und Theoretische Informatik verbinden, als auch Meta-Analysen zu E-Learning und Blended Learning.

Die Inhalte können in den erstellten Lerneinheiten als Text oder Video angesehen werden, zusätzlich enthalten die Lerneinheiten auch Aufgaben zu den Inhalten. Studierende können die Inhalte auf verschiedenen Lernpfaden lernen. Dabei können sie wählen, ob sie vor der eigentlichen Erklärung zunächst einführende Beispiele zu einem neuen Themengebiet sehen wollen, oder auch nach der Erklärung eine zusätzliche Vertiefung ansehen, wenn sie weitergehendes Interesse haben.

Die Lerneinheiten wurden zum Selbststudium und auch zur Selbstkontrolle mittels der Aufgaben erstellt. Zwei dieser Lerneinheiten wurden passend zu einem Kurs zu Formalen Sprachen und Automaten erstellt, den Studierende typischerweise zu Beginn ihres Studiums belegen. Zwei weitere Lerneinheiten wurden für einen fortgeschritteneren Kurs zu Reaktiven Systemen erstellt. In beiden Fällen sind die Lerneinheiten dabei als reine

Ergänzungen zu den Kursen an Universitäten gedacht. Die Kurse bleiben dabei ansonsten unverändert. Des Weiteren wurde ein speziell auf diese Lerneinheiten zugeschnittenes Instrument zur Evaluation entwickelt, mit Fokus auf Motivation und Kompetenzzuwachs. Die Lerneinheiten wurden in sechs Studien an der RWTH Aachen, der Technischen Universität Berlin, der Universität Duisburg-Essen, der Universität Potsdam und der Universität Salzburg evaluiert. Trotz geringer Beteiligung an den Studien, kommt die Analyse zum Ergebnis, dass viele Teilnehmer die Lerneinheiten als hilfreich angesehen haben und die Ergebnisse bezogen auf Kompetenzen leicht positive Tendenzen zeigen. Die Ergebnisse bezüglich Motivation waren uneindeutig, zeigen aber Möglichkeiten für weitere Forschung auf.

Nach Abschluss der Studien wurden die Lerneinheiten für die Allgemeinheit zugänglich gemacht und im Sommersemester 2019 explizit Studierenden in zwei Kursen der Technischen Universität Berlin und der Universität Duisburg-Essen zur Verfügung gestellt. Beides wurde getan, um die Nachhaltigkeit dieser Arbeit zu sichern. Des Weiteren die Möglichkeit diskutiert, wie der in der Dissertation umgesetzte Ansatz für weitere Lerneinheiten wiederverwendet werden kann, nicht nur für die Theoretische Informatik, sondern auch noch für weitere Bereiche.

Contents

List of Abbreviations

CATLM	Cognitive-Affective Theory of Learning with Media
CLT	Cognitive Load Theory
CTML	Cognitive Theory of Multimedia Learning
DFA	Deterministic Finite Automaton
DPDA	Deterministic Pushdown Automaton
FAM	Fragebogen zur Erfassung der aktuellen Motivation *(German name for QCM)*
FLAT	Formal Languages and Automata Theory
FoSA	Formale Sprachen und Automaten *(German translation for FLAT)*
LTS	Labeled-Transition System
MOOC	Massive Open Online Course
NFA	Non-Deterministic Finite Automaton
PDA	Pushdown Automaton
QCM	Questionnaire for Current Motivation
ReSyst	Reaktive Systeme *(German translation for reactive systems)*
UEQ	User Experience Questionnaire
UX	User Experience

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Chapter 1

Motivation and Classification

Courses on theoretical computer science on bachelor university level often have to deal with high levels of frustration as well as high failure rates. The overall aim of this dissertation is to improve the understanding of how e-learning can be used to improve the learning process for theoretical computer science in university courses. Therefore, a solution approach based on supplementing such courses using e-learning is presented and evaluated.

In this section, the importance of theoretical computer science and the aforementioned course problems are discussed, followed by a brief overview of possible explanations for these problems. A general overview of the concept and the topics of the solution approach proposed, implemented and evaluated in this dissertation is given. Afterwards, the relation of motivation and learning is discussed briefly to explain why motivation is one of the main focus points of the evaluation. The section concludes with an overview of the structure of this dissertation. It furthermore presents the main contributions and the publications associated with this dissertation.

Theoretical computer science has many areas like automata theory, computational complexity, computability theory and data structures – to name just a few. It is a relevant and vital part of computer science. Its importance can be seen from the recommendations for bachelor and master computer science programs [Ges16] by the German "Gesellschaft für Informatik" (which translates to Informatics Society). In these recommendations, theoretical computer science is part of several of the outlined content areas. Additionally, the recommendations accentuate the importance of theoretically substantiated concepts and methods for computer science degree programs. In [AILS09], Aceto, Ingólfsdóttir, Larsen and Srba discuss their teaching experiences in courses on one area of theoretical computer science and emphasize that techniques and tools based on theoretical approaches are useful for system design. Armoni, Rodger, Vardi and Verna all stress the importance of automata theory for all computer science students in their position statements in [ARVV06].

As technology development advances rapidly, with high-speed trains, driverless cars or vast amounts of data stored in the so-called cloud, it can be assumed that theoretical computer science will stay relevant in the future with its methods like proving the correctness of algorithms and testing for properties of models. Such approaches can ensure that a machine reacting in accordance with its specifications is not only verified by testing scenarios but has been proven for all possible cases.

Nevertheless, the failure and dropout rates in this area are usually high at universities, both in Germany and other countries. In 2016, out of the twenty courses with the highest attendance rates in the bachelor of computer science program at Technische Universität Berlin, the four courses with the worst success rates all were obligatory courses on theoretical computer science. The mean success rate for these four courses was 48.3 percent, compared to a mean of 69.85 percent for all 20 courses [Str17]. The report to a study of the German Centre for Higher Education Research and Science Studies (DZHW) concludes that computer science study programs, in general, have dropout rates above average [HHS$^+$09]. The report states performance problems of the students as the major reason for dropping out, and explicitly the mathematical emphasis at the beginning of the programs. Such mathematical emphasis is a typical aspect of courses on theoretical computer science, in addition to courses purely concerned with mathematics. Both kinds of courses are usually placed at the beginning of such programs. In addition to such extensive analysis, a large amount of anecdotal evidence by professors, lecturers and teachers can be found in the literature. Schlüter and Brinda state that theoretical computer science is "difficult to learn and to teach" [SB08b, p.2]. Almost the same statement can be found in [CGM04], [CCY03] and [CEK13]. In [Sig07], Sigman remarks that engaging students in introductory courses on theoretical computer science is difficult. Many more sources that mention problems in teaching theoretical computer science, low motivation and failure rates can be found (e.g. [KK13], [FK18], [KF16], [Ver05], [Zin08], [RS04], [CGM04], . . .).

Several reasons for these issues seem plausible. In [Ber15], Bergner discusses general misconceptions as a common reason for computer science students dropping out of their degree programs in general. Inter alia, this might be related to theoretical computer science, as many other typical undergraduate courses for computer science follow the lines of students' expectations more closely. Armoni [CEK13] discusses a lack of abilities of the students to use abstraction in a course on theoretical computer science, and for another course, Sigman states the "mathematical material discourages students" [Sig07, p.1]. Wermelinger and Dias [WD05] also see the mathematical nature as a problem. Verma [Ver05] stresses a lack of hands-on material and exercises for one such course. Gramond and Rodger [GR99] also discern a general lack of hands-on material, the mathematical nature and additionally the lack of immediate feedback when working with paper and pencil for such courses. Although several sources state a lack of motivation for formal courses among students or problems motivating students (e.g. [Ver05], [Zin08], [RS04], [CGM04]), Frede and Knobelsdorf [FK18] argue that problems with certain types of assignments, especially proving assignments, can be found on all performance levels, thus, presumably independent of motivation.

1.1 Solution Approach

From the preceding section, it can be concluded that the learning of theoretical computer science needs to be improved. This section will present a first overview of the solution approach used in this dissertation to achieve this improvement. The general idea is supplementing the courses with e-learning. Nortvig, Petersen and Balle [NPB18] define e-learning (using the term interchangeably with online learning) as learning where the physical classroom "is replaced by the use of web-based technologies offering opportunities for out-of-class learning independent of time, place and pace" [NPB18, p.47]. The combination of in-classroom activities and e-learning is called *blended learning*. In a meta-study on different approaches on e-learning, Siemens, Gašević and Dawson [SGD15] conclude that students performed best when blended learning scenarios were used. They compared these scenarios to course activities solely in-class or solely online. In another meta-study, Bernard et al. also found blended learning to slightly increase the performance of students [BBS$^+$14]. Nortvig, Petersen and Balle discuss that studies with contrary results exist as well, and that the success of such an approach is dependent on how the scenario is implemented [NPB18].

The blended learning scenario used in the dissertation is unusual due to the course content, delivery and other circumstances remaining left unchanged. E-learning is purely being used as a supplement, though one strongly aligned to the course content. Therefore, this dissertation will mostly refer to the general term e-learning. To tackle the aforementioned problems with courses on theoretical computer science, the basic goals of this approach are to give students a wider variety of exercises, facilitated and individual access to learning, and the possibility to learn at their own pace.

The platform used for this approach is a Moodle[1] platform located on a server at Technische Universität Berlin, but separated from the general Moodle of the university. In the following, the term *Learning Unit* will refer to one of the four Learning Units for e-learning created for this dissertation. Each Learning Unit is implemented as one Moodle course. The general aim of the Learning Units is to improve the learning motivation of the students and aid them in acquiring necessary competencies for the corresponding course.

An obvious question here is: Why is motivation part of these general aims? Vollmeyer and Rheinberg [VR00] argue that motivation is one of the key concepts affecting learning. Therefore, studying the motivation of the students is considered insightful. Additionally, as mentioned at the beginning of this chapter, motivational problems in courses on theoretical computer science are brought forward often but were not part of the research in the aforementioned examples.

The Learning Units address course topics in a conversational style. Students can choose between having explanations presented as text or as videos. To a certain degree, they can choose which learning path to follow. The actual content is followed by exercises, implemented as single- or multiple-choice questions. Answering questions gives the students direct feedback on their answer, and questions may be answered repeatedly. If the students have answered a sufficient amount of questions correctly, a bonus page is unlocked, giving the students an open question or an interesting fact or application related to the content. Exercises and an easily understandable set of interactive elements form an essential part of these units. The idea is for students to actively engage with this material, gain knowledge, and step by step, the competence and confidence to solve exercises on the corresponding topics.

These topics are taken from two rather different courses held in similar form at several universities. The first course is called *Formale Sprachen und Automaten (FoSA)* at Technische Universität Berlin. This course is mandatory in similar form for bachelor students in computer science in several universities. It provides an introduction to theoretical computer science, focusing on formal languages and automata theory. In Berlin, it contains some basic concepts of mathematics and proofs as well. The contents used from this course for the Learning Units are the pumping lemma, deterministic and non-deterministic finite automata, the minimization of these automata and pushdown automata. The second course, called *Reaktive Systeme (ReSyst)* at Technische Universität Berlin, is more advanced. It is a course for bachelor students at Technische Universität Berlin. At other

[1] `https://moodle.org/`

universities, this content is mostly part of master courses. Such courses cover introductions to process modeling, bisimulation and the usage of fixed point theory to compute the largest bisimulation in a given labeled transition system. Properties of such a system are characterized using the Hennessy-Milner logic. The Learning Units for this course cover strong and weak bisimulation, fixed point theory in general, and particularly the computation of the largest bisimulation using fixed points for a labeled transition system. Of course, only a small part of theoretical computer science can be covered with the four Learning Units. They are exemplary implementations to implement and test the approach presented in this dissertation.

For each of these courses, two Learning Units were created. The choice to create two Units per course was necessary to enable the research approach later presented in this dissertation.

1.2 Structure

This section will give a short overview how this dissertation is structured. In Chapter 2, the research questions on which the following work is based are derived and discussed. These questions are split in two parts: The first part consists of the so-called preliminary questions that can be seen as the fundament of the Learning Units and can be answered independently of the actual Learning Units. These are followed by the *main* research questions concentrating on how motivation and competencies of the students are affected by the usage of the Learning Units. Chapter 3 answers the preliminary research questions by giving an overview of multimedia learning theories used for the creation of the Learning Units and existing approaches on multimedia-based learning for theoretical computer science. Chapter 4 presents the general concept of the Learning Units, competencies which the Learning Units aim to convey, and explains and discusses the didactical decisions that were undertaken. Chapter 5 presents the main ideas and the structure of the evaluation with insight into the whole evaluation process, followed by Chapter 6, which presents the results of this evaluation approach. Chapter 7 presents a summary of the results, the lessons learned in the process of constructing and evaluating the Learning Units, the hypotheses generated by this work and ideas for further work and studies, and presents the approach undertaken for consolidation of the Learning Units. The appendix contains the so-called digital appendix (Appendix A), with links to the pre-processed data and further evaluation results. This digital appendix is followed by material concerning the evaluation, which was excluded from the main part of this dissertation for readability reasons.

1.3 Contributions and Publications

The main contributions of this dissertation are the development of the general concept of the Learning Units, the implementation of this concept in four Learning Units alongside an evaluation instrument, and the evaluation results. The latter generate feedback on the concept and the concrete Learning Units and additionally, new hypotheses for further research.

This dissertation is based on research funded by the German Federal Ministry of Education and Research (BMBF) under the project number 01PL 17024.

The content of this dissertation has in parts already been published. The following list shortly describes the content of each article and the author's contribution in all cases where the articles were jointly written with others:

- **Arno Wilhelm-Weidner – e-Learning für Theoretische Informatik im LMS Moodle – Konzept und Evaluation** [Wil17]
  In this short article, a description of the concept and ideas for the Learning Units is given. The general study design is presented, as well. The main aim of this article with an accompanying poster presentation on the corresponding conference was, to get further professional feedback on the general approach.

- **Arno Wilhelm-Weidner, Nadine Bergner – Vergleich von Lernstilen und deren Umsetzungsmöglichkeiten im LMS Moodle** [WB18b]
  In this article, an overview of the most important learning styles is presented, followed by possibilities of practical applications in Moodle, used as an example of a learning management system. The section on these practical applications and the outlook were jointly written with Nadine Bergner, all other parts were written solely by the author of this dissertation.

- **Arno Wilhelm-Weidner, Nadine Bergner – On Supplementing Theoretical Computer Science Courses using E-Learning** [WB18a]
  This article presents the didactical concept for the Learning Units and the study design for their evaluation. Additionally, the results of the two studies in Berlin are presented and discussed. The paper was mainly written by the author of this dissertation, Nadine Bergner accompanied and advised the work in general and improved the presentation of the content in the article.

- **Arno Wilhelm-Weidner, Uwe Nestmann – On the User Experience of Moodle as a Tool for e-Learning in Theoretical Computer Science** [WN18]
  In this article, the general design of the Learning Units is presented alongside evaluation results on user experience and a discussion of these results. The paper was mainly written by the author of this dissertation, Uwe Nestmann improved the presentation of the content in the article.

- **Florian Schmidt, Franz-Josef Schmitt, Laura Böger, Arno Wilhelm-Weidner, Nicole Torjus – Digital Teaching and Learning Projects in Engineering Education at Technische Universität Berlin** [SSB+19]
  In this article, a brief overview is given of the Learning Units and the first results alongside other projects on the improvement of teaching in different areas, all in the context of the same research project funded by the German Federal Ministry of Education and Research (BMBF). Solely the section concerning the Learning Units was written by the author of this dissertation.

Chapter 2

Research Questions

The first chapter gave an overview of the general motivation for this dissertation, the structure of the following work, its main contributions and the respective publications. This chapter will give a short overview of major learning theories as a basis. Past developments will be discussed where other approaches were used to improve the learning of theoretical computer science, deriving the so-called preliminary questions in the process. These preliminary questions built the foundation of the design of the Learning Units, considering multimedia learning theories and existing approaches for the area. Afterwards, the main research questions will be presented with the aim of measuring the effects of using the Learning Units on motivation and learning outcomes.

The dissertation uses the methodology of design-based research, which combines design under consideration of existing learning theories with empirical research in learning for better understanding and improvement of learning theories [Des03]. Reinmann [Rei05] states that important criteria of design-based research processes are innovation, usefulness and sustainability. All three aspects will be part of the Learning Units that are designed and evaluated in this dissertation. The Learning Units are innovative, as to the best of the author's knowledge no such approach currently exists elsewhere. Other approaches concerning this area will be discussed in this chapter and later in Section 3.3. The approach aims for usefulness, as students are given further possibilities to learn their course content. The approach is sustainable, as it can easily be reused in other institutions. The reuse of the Learning Units is discussed in Section 7.6. Another important aspect of design-based research is the iterated cycle of theoretically founded design, evaluation of the approach and re-design in the sense of a formative evaluation. For the approach of this disseration, this aspect was implemented by employing such cycles in the development of the Learning Units. As described in Chapter 5.2, tests and consultations with professors, assistants and students were used to improve the Learning Units. Additionally, the whole evaluation (Chapter 5) can be seen as serving the purpose of such a cycle in a broader sense. The insights gained will also be used for further development of those Learning Units beyond this dissertation.

In Chapter 1, it was concluded that there is need for improvement in the learning of theoretical computer science. As a step towards this, it is useful to have a look at how the process of learning works best. Therefore, at first, a short overview of the three major learning theories is given.

Behaviorism concentrated on observable behavior of learners. The researchers analyzed how “good” behavior (e.g. a correct answer) could become more likely by positive reinforcement. Vice versa, they analyzed how “bad” behavior could become less likely by using negative reinforcement. However, behaviorism could not explain many phenomena concerning learning. The second major theory, **cognitivism**, aimed to understand how the human memory and the cognitive processes surrounding learning worked. Assumptions about the process of learning, considering cognitive changes in short-term and long-term memory were built. The third major learning theory, **constructivism**, added the necessity of the learner actively engaging in learning and constructing knowledge to this. Preliminary knowledge and experiences of the learner are an important aspect of learning as well. Current approaches on educational research mostly combine elements of cognitivism and constructivism, often including motivational considerations. [GG11a]

The general design of the Learning Units is such a combination of cognitivist and constructivist ideas. For the presentation of multimedia content and learning with it, further specialized theories have been developed and researched over the years. These theories and the resulting design recommendations will be used for the design of the Learning Units. Therefore, the first preliminary question is:

> Preliminary Question 1
>
> How do factors of cognitive structures influence how the elements used in these units, like text, videos and quizzes, help students learning?

This question comprises two aspects: On the one hand, how these multimedia elements convey information to the learners and which ways of implementation can influence this in positive or negative ways. On the other hand, how the students need to actively process this information to achieve learning and what the factors in this process are.

This preliminary question will be answered in Section 3.1.

2.1 The Research Gap

This section will take a closer look at the problem area of courses concerning theoretical computer science. This is done by consideration of approaches to overcome problems in teaching and learning in this area. Over the past decades, several approaches have been tried out in this area. Most of these approaches aimed to reduce failure rates, to improve the learning in the courses in general or to increase the motivation among students. Nevertheless, to the best of the author's knowledge, motivation has in these approaches never been measured to a similar extent as in this dissertation. The following overview is not complete but extensive, concentrating mainly on research and teaching approaches in the introductory phases of the study programs. An exceptionally large amount of papers was found on formal languages and automata theory (FLAT), presumably because such courses are often introductory courses for theoretical computer science. This section will, with a few exceptions, concentrate on published research papers.

The approaches have been categorized by the author distinguishing between different uses of e-learning. One category comprises those mainly restructuring the course material or course structure without e-learning. This category is called "Didactical Offline Approaches" and discussed in Section 2.1.1. The next category comprises approaches focusing on tool-usage for more hands-on work inside or outside the classroom. This category is called "Tool-Based Approaches" and discussed in Section 2.1.2. Another category comprises approaches with explanatory focus on the content. This category, called "E-Learning Approaches", is discussed in Section 2.1.3. More extensive studies conducted on such approaches are discussed separately in Section 2.1.4 under the heading "Approaches with Studies". Finally, studies on the teaching and learning of theoretical computer science where no particular approach was tested are considered. These studies focus on understanding the problems in this area. This overview is simply called "Studies" and discussed in Section 2.1.5.

2.1.1 Didactical Offline Approaches

Several approaches concentrate on alternatives to improve courses on theoretical computer science. Knobelsdorf and Kreitz [KK13] reworked a FLAT course didactically from a constructivist point of view. They mainly aligned lectures, tutorials and homework to intertwine better, and were able to reduce failure rates. These changes are described in more detail by Knobelsdorf, Kreitz and Böhne [KKB14]. No reports of a similar reduction of failure rates by introducing similar measures seems to have been reported elsewhere.

For example, in the FLAT course at Technische Universität Berlin similar measures are taken. The failure rates in this course are much higher than the six percent reported in the paper. Other approaches concentrate less on organizational aspects than on alternating the presentation of the content. Hämäläinen [Hä04] states that the topics in her courses, namely the theory of computability and computational complexity, are very difficult for students and introduces a problem-based learning approach. Here, students were given problem descriptions in each session to work on and solve in groups. For example, students were asked to search amongst a set of e-mails, leading to a better understanding of regular expressions. Of 63 students taught in this problem-based way, 56 completed the course. Hämäläinen states that usually, less than 50 percent pass the course. Reed and Sinclair [RS04] attempt to improve student motivation. In their paper, they provide example exercises to help motivate students beyond what is usual. These exercises are programming examples, illustrating the usefulness of formal specifications, clearly described invariants and formal analysis. No clear measure of success is mentioned but Reed and Sinclair state that the usage of these problems engaged and motivated students. Goldreich [Gol06] outlines ideas on how to present material concerning the P-vs-NP problem best, concentrating on its fundamental nature. Results or first impressions of applicating these ideas are not reported. Sigman [Sig07] promotes the use of discovery learning in a FLAT course to further engage students into the topics. Students were presented with the basic problems of computability and intractability and a basic outline of these problems to different automata models and then worked on solving problems in the lessons or presented each other parts of the content. Only four students participated in the course. Even though all four successfully completed the course, Sigman discusses that results of the course can only be seen as anecdotal evidence. Zingaro [Zin08] shortly describes the use of a particular textbook by him, applying programming examples from various problem domains to engage students in a FLAT course. No results of the usage of this textbook are reported. Aceto, Ingólfsdóttir, Larsen and Srba [AILS09] discuss their didactical experiences of teaching concurrency theory best, also with a general focus on course structure. They do not discuss results beyond an increase in student satisfaction. In [Kno15], Knobelsdorf examines the potential to teach theoretical computer science courses from the viewpoint of situated learning. The idea is to include the iterative development of theories including failure instead of merely presenting the existing theories. No results are reported as the paper focuses on the presentation of general ideas for teaching theoretical computer science rather than any application of these ideas in a course.

Books can also be found on the notion of improving the presentation of material on theoretical computer science that exist less in a course context. Examples are books by Hromkovič [Hro09], describing the origins of computer science in a theoretically grounded way, or a book by Dewdney [Dew01] discussing major "landmarks" of computer science.

Considering the research gap for this area, hardly results are reported for the approaches and ideas presented in this section. Many of the authors discuss student difficulties in learning theoretical computer science. Most approaches focus on changing the situation in the classroom. Only the textbooks give students an opportunity to learn beyond the time of the lessons. Textbooks have been available on these topics for a long time, and the student difficulties still seem to persist. This leads to the assumption that either these textbooks are not helpful enough to students as a way of learning or the textbooks themselves do not convey the content in a way helpful enough.

2.1.2 Tool-Based Approaches

A large number of papers can be found where instructors used or created tools to give students a more hands-on experience of theoretical computer science topics. Most of these tools allow to test, work with, or even create examples, often automata, as an addition to or replacement of traditional pencil-and-paper exercises. Chesñevar, Cobo and Yurcik [CCY03] distinguish two main categories of tools in their comparison of existing tools on FLAT topics: (1) Those that contain several related concepts and (2) those tools that are created to work with one specific class of automata. Of the former category, JFLAP[1] is by far the most well-known, created by the group surrounding Professor Susan Rodger at Duke University. The latest version was released in 2018 and allows to create and test many classes of automata up to Turing machines. Users can also transform non-deterministic to deterministic automata or try out the pumping lemma. Many approaches have been reported where JFLAP was included, while more classes of automata and functions were added over the years, e.g. by Procopiuc, Procopiuc and Rodger [PPR96], Gramond and Rodger [GR99], Cavalcante, Finley and Rodger [CFR04], Verma [Ver05], Rodger, Bressler, Finley and Reading [RBFR06] and Rodger, Lim and Reading [RLR07]. In all of these papers, the authors stress the need for more hands-on material for students and more interactivity.

A slightly different kind of approach where JFLAP is combined with tools from category 2 can be found. For example, Rodger et al. [RBL+97], where the authors mainly

[1] `http://www.jflap.org/`

look at JFLAP, Pâté for parsing grammars and PumpLemma for proving languages are not regular. It is reported that student feedback on these tools was positive. No further results are reported. Hung and Rodger [HR00] introduced JFLAP and Pâté in a course and discuss benefits of this approach. No results are reported. Chesñevar, González and Maguitman [CGM04] state a lack of motivation and interest by the students as their leading cause of action. They introduced didactic strategies, mainly a historical view on the content, in combination with JFLAP and several other simulators in their course. They report no results beyond a more satisfying experience for the students.

Over the years, many papers have been written on similar approaches that will subsequently be summarized. Where results of the approaches are reported (beyond merely students enjoying them), this will be stated explicitly. In [CGS63], Coffin, Goheen and Stahl already describe a program to simulate a Turing machine and emphasize its usefulness for teaching students, even though they do not go into detail on this matter. Hannay [Han92] created a Hypercard program with simulation models for finite state automata, pushdown automata and Turing machines. Boroni et al. [BEG⁺96] describe the software DynaLab, created for interactive lecture demonstrations to analyze the behavior of algorithms, e.g. experimenting with intractable problems. They report that one student tested the software without prior training and was successful in conducting an experiment on time complexity of a program. Robinson et al. [RHND99] present the Java Computability Toolkit to construct, modify and run finite automata and Turing machines. McDonald [McD02] created a tool to work with pushdown automata. Vieira, Vieira and Vieira [VVV04] created Language Emulator, a toolkit to help students understand automata theory, with feedback on their solutions. 95 percent of students stated in a first application that they found the tool helpful. The number of participants of this survey is not reported. Hielscher and Wagenknecht [HW06a] developed AtoCC[2], a learning environment consisting of serveral tools for FLAT courses to actively interact with automata. AutoEdit [HW06b] was developed alongside to work with automata.

As a recent further development of AtoCC, Hielscher and Wagenknecht describe in [HW19] the web-based learning environment FLACI[3] that allows students to experiment with the creation of automata and learn basics concerning formal languages and regular expressions. As an application of automata theory, FLACI enables users to construct compilers. White and Way [WW06] describe jFAST explicitly as an alternative to JFLAP, where students can explore and visualize finite state automata. This program was tested in

[2] www.atocc.de
[3] www.flaci.com

a lesson with 18 computer science students. 16 of these students found jFAST easy to use and all of them found that using it alongside their university course would enhance their understanding of automata theory. Stoughton [Sto08] developed Forlan, a formal language toolset written in ML to experiment with algorithms. Garcia-Osorio et al. [GMJG08] briefly introduce a new version of the tool Toth for FLAT courses, for creating and checking automata. Schäfer et al. [SHL+13] built a serious game for mathematical logic and discuss student difficulties with mathematics and theoretical computer science intensely in their paper. This discussion is based on interviews with 12 students. Students explicitly stated to have problems concerning the application of mathematical methods and proving. All the interviewees named courses on mathematics or theoretical computer science to be the most difficult. Ten participants tested the created game and assessed it to be highly useful, albeit some usability difficulties existed. Additionally, two experts were asked to evaluate the game and found further problems concerning usability. Böhne, Kreitz and Knobelsdorf [BKK16] used the theorem prover Coq[4] to enable students to prove interactively. Pereira and Terra [PT18] created FLApp, an Android app for interactively working on exercises in the area of FLAT.

Some approaches want to take advantage of the fact that computer science students, in general, can be assumed to be interested in programming. Wermelinger and Dias [WD05] developed a tool for FLAT courses in the language Prolog, with the idea that students can enhance the tool further. Korte et al. [KAPG07] enable students to learn by building a game in a given framework based on a set of rules, with one of the examples they describe based on automata theory. They tested their approach with 118 students in their first year working on one assignment over a period of two weeks. The students could either copy an existing game or work on their own game. The approach was tested furthermore with another assignment by the same students in their following second year. The first assignment was given in a course on programming, the second assignment in a FLAT course. The students created games using automata. 87 percent of these students in the second course completed their game. Further results are not reported. Crescenzi, Enström and Kann [CEK13] state that students have problems with the concept of NP-Completeness. They used an action research approach combining visualization and programming tools. This was tested in two different courses. One course had twelve participants, the other course was held twice with 140 students in the first run and 150 students in the second run. The survey consisted of questions on the helpfulness and meaningfulness of the used

[4] `https://coq.inria.fr/`

approach. Student results indicate overall that they found the approach both helpful and meaningful. Students attending (almost) all of the activities of the approach also seemed to improve their outcome in the homework assignment.

Most of the tools described above do not seem to be developed anymore, or at least not publicly, with JFLAP being the exception. As a theorem prover used mostly in other directions than teaching, Coq is also still being developed further.

Concerning tools, Hundhausen, Douglas and Stasko [HDS02] conducted an interesting meta-analysis in another area of computer science, the visualization of algorithms. They stated that even though many tools had been developed for this area, there still was no widespread use, which seems to be similar for theoretical computer science, with the possible exception of JFLAP. They analyzed the educational effects reported in papers and concluded that there are mixed results on educational effects, but that the effects were most in favor of the tools when students are actively engaged while using them, being able to create and test their solutions. To the best of the author's knowledge, no such meta-analysis exists for the aforementioned tools, but reports on educational results would also be interesting in this area.

For many of these approaches, no or only a few results were reported. This aspect of the research gap is similar to the preceding section. Another aspect is that if students did not fully understand the theoretical parts of the lectures, working with tools might not help them to a meaningful learning experience. The results of, e.g. creating automata without knowing the context might as well be confusing.

2.1.3 E-Learning Approaches

The approaches mentioned in this section focus on the explanation of the content. Content is most often presented as text or as video. These approaches are to a more considerable extent self-contained than those focusing on tools in the section before.

Early approaches were created by Barwise and Etchemendy with one software called Tarski's World [BE93a] to test formulas in first-order logic, and another software called Turing's World [BE93b] to build and run Turing machines. Both were accompanied by extensive textbooks with explanations of the content and exercises to be done with the respective software. They report no evaluation of their software and books.

In the area of the so-called intelligent tutoring systems, Devedzic, Debenham and Popovic [DJD00] developed the FLUTE system, an intelligent tutoring system for FLAT. The idea was that instruction depended on the learning capabilities of students. The system registered the progress of the students and could offer hints. Progressing to the next part was possible when the content had been mastered. FLUTE could, according to the paper, be used to show content as text, present exercises and be upgraded by instructors. The described version was developed for Windows 98. Devedzic, Debenham and Popovic briefly compare FLUTE to other intelligent tutoring systems. The main advantage of FLUTE, according to them, is its systematic design and complex student model. They report no evaluation results. Several years later, Pillay and Naidoo also developed an intelligent tutoring system and presented their idea of automata generation to give immediate feedback in [PN06]. The idea was that their system allowed students to create and test automata, could correct their solutions and even give feedback. Generating solutions for this feedback worked well in their tests. No further evaluation results are reported. Tscherter [Tsc04] developed Exorciser[5] as an automated tutor in a similar approach, giving more control over the whole process to the students. The students could solve exercises and get interactive feedback. The system was also tested in a study where it seemed to be helpful for the students. In a comparative study with 195 students, the test group performed significantly better than the control group in a test using content questions. Tscherter states, however, that approaches where automated feedback in such detail is possible are limited to very particular domains. Exorciser could also be seen as a tool-based approach but it was integrated in this category because of the concept of individual feedback.

With the idea of learning online, a hypertextbook on the theory of computing was created and described by Grinder et al. [GKL$^+$02] and Cogliati et al. [CGG$^+$05]. The hypertextbook[6] contained content in many different formats (e.g. text, sound, pictures, video clips, etc.). Content was related via hyperlinks, and so-called active learning models, which were applets where students could work with examples of the content. They report no evaluation results.

Several approaches that were combined with university courses can also be found. Berque, Johnson and Jovanovic [BJJ01] discuss a theory of computation course taught with pen-based computers, whiteboard and an improved didactic strategy. This course was taught for thirteen students. On several occasions, the students were asked whether they preferred this to the traditional approach and more similar questions. Eleven students preferred the electronically enhanced variant. Nine students assumed to be more attentive

[5] `https://www.swisseduc.ch/informatik/exorciser/`

[6] Old snapshots of this hypertextbook can be found at `https://www.cs.montana.edu/webworks/webworks-home/projects.html`

in this scenario than a traditional one. Brauer et al. [BHKS03] introduce exercises in the context of an adventure story to motivate students. Additionally, they use a tool called Grail to work with automata and solve puzzles. The authors report no detailed evaluation results. Rohde and Thomas [RT03] present a system to capture voice and annotations in combination with slides in lectures on theoretical computer science. They emphasize the importance of working with formulas in this area. An additional software was developed and used to pose exercises. This approach was used in three courses, where the first one was attended by 400 students, the second and third each by 150 students. In a first evaluation, students found the system useful but interestingly voted for a combination of real and e-lectures. Rohde and Thomas state that exam results were improved in the year of the approach. Nestmann and Wilhelm[7] [NW14] describe an approach to add screencasts[8] to a FLAT course as a supplement. No evaluation results are reported.

Even though no research papers explicitly on these courses could be found, a course on theoretical computer science [Uda] was located on the platform Udacity. It is concerned with topics such as complexity analysis, reductions or NP-completeness. The lectures consist of videos, quizzes and a forum for discussions. Additionally, at the University of Stanford, an online course on automata theory [Ull] exists, consisting of videos, homework and a final exam.

An interesting collection of tools, exercises and programs (mainly for secondary education) can be found at SwissEduc [Swi]. Exorciser is also part of this collection. Two further tools will be described here: Kara and InfoTraffic. These were chosen as they are both accompanied by dissertations and research papers. Both programs are enriched with examples and explanations and therefore were included in this section. Kara is presented by Reichert [Rei03]. This environment comprises inter alia tools to learn programming, to introduce Turing machines and to learn basic concepts of concurrency. This is done in a very interactive nature. In most cases, the user controls a ladybug through a digital environment. In the case of Turing machines, the user controls the head of the Turing machine through a two-dimensional world of zeros and ones. For all Kara tools, users get exercises and corresponding solutions and explanations. InfoTraffic is presented by Arnold in [Arn07]. It consists of several programs where students can work on regulating or controlling traffic. On such problems they can learn logic, as e.g. presented by Arnold and Hartmann in [AH07], or the students can learn more about queues, as presented by Arnold, Langheinrich and Hartmann in [ALH07]. Both the Kara and InfoTraffic system

[7] Wilhelm is the birth name of the author of this dissertation.
[8] `https://www.youtube.com/theuberlin`

were not experimentally evaluated. For the Kara tools on Turing machines, 131 students were asked in a survey conducted in a course at ETH Zürich whether they benefitted in their learning and whether they liked the user interface, both using very direct questions and the results were highly positive [Rei03].

Content videos on single topics without a larger surrounding course structure (e.g. [The] on Turing machines) were not considered further for this overview or the later analysis.

Considering the research gap, many of the articles do not present evaluation results. Implications for research and theory are seldom integrated. Interestingly, none of the approaches seems to have been adopted by a large part of the scientific community. This holds independent of the evaluation results.

2.1.4 Approaches with Studies

Only a few of those many approaches in the areas considered were evaluated extensively. This includes the approaches described up to this point. Extensive here means evaluation beyond the use of questionnaires in the respective courses or similar ways. This section contains approaches where studies larger than that were conducted.

Grinder [Gri03] evaluated the Finite State Automaton Simulator (FSA Simulator), which could be used by students to work with finite state automata. In a comparative study, a test group ($n = 52$) that used the simulator and a control group ($n = 44$) were asked to solve exercises and afterwards answer a further set of content questions. The students in the test group spent considerably more time on the exercises, playing around with the examples. Overall, the success rate of the test group was improved, but there was no significant difference to be found. Habiballa and Kmet [HK04] tested a didactical approach in combination with the usage of tools in a comparative study with a control group ($n = 28$) and a test group ($n = 28$). Their tools yielded positive results, but students had problems to transfer the new knowledge to the theory. Rodger et al. [RWL+09] conducted an extensive study on FLAT courses where JFLAP was used as a supplement. The two-year study with fourteen participating universities, one university with a control group, yielded overall positive feedback. On the downside, students stated that JFLAP had little use for them regarding exam preparation. Crescenzi, Enström and Kann [CEK13] evaluated their action research approach by using post-questionnaires in the two courses the method was used in with positive results, yet without further statistical analysis. In [SAC+19], Singh et al. describe an Android app, called Automata Simulator, for creating and simulating automata. This app was tested with 185 students in a course. Those students in this course that used Automata Simulator and JFLAP performed slightly better in a test than those using only JFLAP as an additional tool for the course.

As discussed in the last section, the system Exorciser by Tscherter [Tsc04] yielded significant results in a comparative study.

The approaches presented in this section were researched to different degrees. Even though results are mixed, overall hands-on tools seem to be an interesting direction for improving the learning of theoretical computer science and deepen the students' understanding. However, these approaches integrate only a limited amount of explanations and presentation of the content. Imparting the actual concepts still seems to be expected to happen wholly in the university courses. Based on the many aforementioned reports of student problems with these courses, a supplement with a stronger focus on content might be helpful.

2.1.5 Studies

This section contains studies where researchers tried to find out more about learning theoretical computer science without introducing a solution approach themselves. Armoni and Gal-Ezer [AG06] conducted a study with 63 students in one FLAT course to find out more about student usage of abstraction and reduction. Both are essential qualities where theoretical computer science or maybe even computer science in general are considered. They concluded that the students used less abstraction than expected. In a follow-up study, Armoni [Arm09] used homework and exam results from two universities in a mostly quantitative analysis to analyze how students use reduction. Undergraduate students did not seem to use reduction as a general problem-solving strategy, even when it would have been useful. Pillay [Pil10] conducted a study to find out what the learning difficulties of students in a FLAT course are. She also analyzed test results as well as the solutions students submitted after weekly tutorials and found several problem areas (e.g. the pumping-lemma, the construction of pushdown automata and several more). The main problem, following her analysis, was the students' lack of problem-solving skills and their inability to conceptualize proofs. Knobelsdorf and Frede [KF16] observed students in a qualitative study on a theory of computation course while solving their homework. They found a lack of work proficiency and familiarity with the necessary methods to solve exercises in their study. A self-regulated approach combined with individual feedback for exercises like the one presented in this dissertation might help in developing such skills if the students' interest in using it can be sparked. In [FK18], Frede and Knobelsdorf analyzed the homework and exam results of students in the FLAT course at Technische Universität Berlin in a quantitative study – the same course where the Learning Units were evaluated one year later. An exploratory data analysis was conducted, with the interesting result that all students seemed to have problems in specific assignments independent of their final exam results. In several cases, students had problems with content where the Learning Units will be used as a supplement in the course from now on.

2.1.6 From Gap to Question

Much has already been done to improve the learning and teaching in the area of theoretical computer science. This can be seen by the overview given so far in this chapter. The majority of approaches used tools to allow students a more practical way of working with the material. Approaches explaining the content to students existed to a much lesser extent. Moreover, only few of all these approaches were combined with more extensive research approaches like the one chosen for this dissertation. The Learning Units constructed in this dissertation focus on additional opportunities to learn content in a self-regulated way and to test student competencies with questions giving direct feedback. For this, the existing hands-on approaches are not of interest. The main focus is on the existing e-learning approaches (Section 2.1.3) as well as the studies considering student problems in this area (Section 2.1.5). For the design of the Learning Units, it is important to review and analyze what the reported problems for students are and whether certain criteria in such e-learning approaches have proven useful. The focus here is on theoretical computer science, especially automata theory and concurrency theory. The second preliminary question therefore is:

> Preliminary Question 2
>
> Which criteria for multimedia-based learning existed in previous studies on theoretical computer science and what effects were reported?

This preliminary question will be answered in Section 3.3.

2.2 Measuring the Effects

The main aspect of this work is the conception, didactical analysis and implementation of the Learning Units. Furthermore, the evaluation will address two questions – the effects of the Learning Units on motivation, and the effects of the Learning Units on the competencies of the students. The basic idea behind these research questions is whether changes can be measured regarding the motivation or competencies of the students when the Learning Units are used. Both main research questions revolve around the idea how usage of the Learning Unit affects the students considering their motivation and competencies. *Affecting* here could mean improving or impairing competencies or motivation. It is also possible that the usage of the Learning Units has neither effect on the one aspect nor on the other.

In general, motivation is seen as an important requirement for successful learning to happen, as e.g. discussed extensively by Spinath [Spi11]. Moreno, whose cognitive-affective theory of learning with media (CATLM) will later be used in Chapter 3 as one of the theoretical foundations for designing the Learning Units, states that “motivational factors mediate learning” [Mor05, p.4]. Low motivation is also particularly often considered a source of problems for students in courses on theoretical computer science. Many of the aforementioned approaches and studies are (at least as a reason to introduce the approach) concerned with motivational problems of the students (e.g. [DJD00], [BHKS03], [RS04], [CGM04], [CGG+05], [Ver05], [KAPG07], [Zin08], [SHL+13]), even though Frede and Knobelsdorf [FK18] question this assumption in general. The corresponding main research question is:

> Research Question 3
>
> How is the learning motivation of the students in a course on theoretical computer science affected by using such an additional learning unit compared to that of students using solely “classic” teaching material?

The “questionnaire for current motivation” (QCM) [RVB01] will be used to measure the current learning motivation in the surveys for the respective topics. The questionnaire will be discussed in more detail in Section 5.4. For now, the relevant aspect is that the questionnaire consists of four scales: *interest*, *anxiety*, *probability of success* and *challenge*. Methodically, students are presented content questions concerning the content of the Learning Units in each study at three points in time: In the beginning, after the first two weeks and then another two weeks later at the end of the study. Each time, students are asked to think about how they would answer or solve these content questions (without actually solving them yet). Directly afterwards, the students fill out the QCM based on their feelings, measuring their motivation towards these questions.

The *interest* scale measures how much students appreciate the content in question. The assumption is that this will not change throughout the study, as the content stays the same independent of the presentation via the Learning Units. Therefore, the first hypothesis is:

- The value for *interest* is not affected by usage of the Learning Unit.

The scale *anxiety* measures the negative stimulus of failure. The assumption here is that a higher level of preparation by using the Learning Units should reduce the *anxiety* of the students. Therefore, the second hypothesis is:

- The value for *anxiety* decreases after usage of the Learning Unit.

The scale *probability of success* measures how safely one assumes to score well in a given test or exercise. The assumption is that this value will increase, as the learners should feel more confident after more solid preparation. Therefore, the third hypothesis is:

- The value for *probability of success* increases after usage of the Learning Unit.

The scale *challenge* measures how much the given test or exercise is seen as a challenge to perform in. The assumption here is that this value will decrease, as the learners should feel well prepared after using the Learning Units. Therefore, the fourth hypothesis is:

- The value for *challenge* decreases after usage of the Learning Unit.

Another aspect of interest for an educational approach like this is how (and whether) it affects the learning outcomes of the students. As will be discussed in more detail in Section 4.1, currently there exist no validated measuring instruments for competencies in the concerned areas, but the questions for the surveys were devised based on the competencies intended to be conveyed, experience with university courses on these areas, and in consultation with professors and fellow research assistants. The corresponding main research question is:

Research Question 4

How are the acquired competencies of the students in a course on theoretical computer science affected by using such an additional learning unit compared to that of students using solely "classic" teaching material?

What the desired competencies of the courses are depends on the respective content of the courses. These competencies will be presented alongside the sources they are based on in Section 4.1. The general research hypothesis on this research question is:

- Participants demonstrate the competencies better after usage of the Learning Units.

In the context of this dissertation, both main research questions are refined from students in such a course to those students that participated in the studies. It is important to note that this dissertation can only answer those research questions with regard to the topics used in the Learning Units and the concrete Learning Units created for this dissertation.

2.3 Research Question Overview

After the research questions have been developed up to this point in the chapter, this section serves as a reference whenever it might be necessary to look up the preliminary or main research questions.

2.3.1 Preliminary Questions

1. **How do factors of cognitive structures influence how the elements used in these units, like text, videos and quizzes, help students learning?**

2. **Which criteria for multimedia-based learning existed in previous studies on theoretical computer science and what effects were reported?**

2.3.2 Main Research Questions

3. **How is the learning motivation of the students in a course on theoretical computer science affected by using such an additional learning unit compared to that of students using solely "classic" teaching material?**

4. **How are the acquired competencies of the students in a course on theoretical computer science affected by using such an additional learning unit compared to that of students using solely "classic" teaching material?**

2.4 Methodical Overview

So far, this chapter worked out an overview of the research gap concerning approaches towards the improvement of teaching and learning of theoretical computer science and then derived the four research questions. This section gives a short overview of the chosen research methods in the general process of a design-based research approach, as described at the beginning of this chapter. To answer the research questions, it is – beyond conception and implementation – also necessary to evaluate the Learning Units concerning motivation and competencies, and additionally to evaluate how the participants experience working with the Learning Unit to learn more about beneficial or adverse factors of the design and implementation. These parts of the evaluation can be found in Section 6.3.

Consistent with the ideas of design-based research, the design of the Learning Units will be (1) based on theoretical foundations, (2) practically implemented and (3) evaluated and analyzed for further development:

(1) To answer Preliminary Question 1, a meta-analysis on theories concerning the cognitive aspects of multimedia learning will be conducted (see Section 3.1). This will be used as a foundation to derive design recommendations that form the cornerstones of the conception of the Learning Units. To answer Preliminary Question 2, another meta-analysis will be conducted integrating approaches with e-learning and the studies on students' problems concerning the learning of theoretical computer science (see Section 3.3). A considerable amount of design choices of the Learning Units will be based on this meta-analysis.

(2) Afterwards, in Chapter 4, the four Learning Units will be constructed and implemented based on the theoretical results and didactical considerations. The Learning Units are created in Moodle as a supplement for two university courses – two Learning Units for each course. For this, the competencies to be conveyed are analyzed based on the competencies for similar courses. In the process, a formative assessment is undertaken by field experts from theoretical computer science as well as students, education experts and fellow research assistants, both from the area concerned, and from didactics. Additionally, the concept is presented and discussed at several conferences.

(3) The empirical evaluation (see Chapter 5 for an overview) takes place in six university courses in five cities: Aachen, Berlin, Duisburg[9], Potsdam and Salzburg. The counterbalanced repeated-measures design of those studies was chosen on the one hand

[9] The study took place in the city of Duisburg at Universität Duisburg-Essen. The different names might lead to confusion. This university is the result of a fusion of two universities. In most cases, the university name will be used instead of the city name throughout this dissertation.

to balance out individual differences even further than the group separation does, and on the other hand so that all involved students get to use one of the Learning Units. The assumption was that participating in such an experiment and then solely being part of the control group would lead to frustration that might negatively influence the results. In each study, participation is voluntary. Participants are separated in two groups A and B based on the results of an initial survey. Afterwards, group A can use the course's first Learning Unit for two weeks, followed by a survey for both groups. After this survey, group B can use the course's second Learning Unit for two weeks, again followed by a survey. The two latter surveys include questions on motivation and competencies, as well as questions concerning the usage of the Learning Units. Apart from the necessary changes in content questions, the surveys are equal for both university courses in question.

The analysis of the evaluation can be found in Chapter 6. It is followed by resulting further research hypotheses, an overview of the lessons learned in the process, ideas for further research and development concerning the Learning Units, and insights into the further use of the Learning Units beyond this dissertation (see Chapter 7).

Chapter 3

Theoretical Background

In the past two chapters, the initial motivation for the approach conceptualized and implemented in this dissertation was presented, followed by an overview of the research in the area of teaching theoretical computer science. Afterwards, the research questions were derived. In this chapter, the two preliminary questions will be answered by meta-analyses concerning cognitive theories and existing multimedia solutions for theoretical computer science. Furthermore, the influences of different learning styles and study results on student problems in courses, on FLAT topics especially, will be discussed. Based on these aspects, design recommendations are summarized in Section 3.5. These recommendations will be used for the design of the Learning Units (see Chapter 4).

3.1 Cognitive Theories

Based on the general idea to design instructional material in a way to facilitate learning, several theories have been proposed over the past decades. Three important interrelated theories that have been investigated empirically will be discussed in the following, alongside their implications for instructional design:

- The cognitive load theory (CLT) was initially presented by Sweller in [Swe88],
- the cognitive theory of multimedia learning (CTML) was initially presented by Mayer in [May01] and
- the cognitive-affective theory of learning with media (CATLM) was initially presented by Moreno in [Mor05].

All these theories are empirically well-grounded and result in design recommendations that can be implemented and realized in the Learning Units. Interestingly, Shaffer, Doubé and Tuovinen [SDT03] explicitly recommend the application of the CLT and its further developments to computer science education.

The following analysis considering these three theories will answer Preliminary Question 1: “How do factors of cognitive structures influence how the elements used in these units, like text, videos and quizzes, help students learning?”

3.1.1 Cognitive Load Theory

The following section summarizes the main points of the CLT and its implications for the design of multimedia learning material. As discussed by Sweller in [Swe05], the CLT was further developed and empirically investigated by several researchers over the years. Sweller emphasizes the importance of designing learning material based on the knowledge of human cognitive structures to improve learning. According to the theory, too much cognitive load can impede or even inhibit learning. Therefore, learning difficulty can be reduced by improving instructional design. He distinguishes different kinds of cognitive load (intrinsic, extraneous, germane) that will be explained in more detail later. The central assumption of the cognitive load theory is that under the right circumstances, cognitive load can be reduced by instructional design considering cognitive aspects. If not explicitly stated otherwise, the explanations in this section on the CLT will follow [Swe05] by Sweller.

In [Swe88], Sweller expresses the assumption that there are some forms of problem-solving – which is used heavily, for example, in the teaching of mathematics – that may interfere with the learning process. He observes structural differences in how novices and experts solve problems throughout different domains, where experts can perform steps towards a given goal immediately using their knowledge and experience, while novices need to use more general, unspecific methods. According to Sweller, the reason for this difference lies in different cognitive structures the experts have acquired. He defines these so-called “schemas” as “a structure which allows problem solvers to recognize a problem state as belonging to a particular category of problem states that usually require particular moves” [Swe88, p.3]. For example, a schema allows to recognize letters in different shapes, sizes and styles for the recognition of handwriting, or to know how to solve a specific type of exercise. Schemas are cognitive constructs which help categorizing information, containing relevant information and understanding how to use this information. Such categorization of information can be done consciously with high effort, but through practice it starts to be automated, and the effort is reduced.

The cognitive structures the CLT relies on, are long-term memory and working memory. Long-term memory is seen as a very large information storage, also containing the aforementioned schemas that have already been learned. Sweller defines learning as an alteration in long-term memory and emphasizes that schema acquisition is an important form of learning. According to Miller [Mil56], the working memory can only hold about seven elements of information at a time. Sweller refers to this, but limits this number even further and states that working memory "can probably process in the sense of combine, contrast, or manipulate no more than about 2-4 elements" [Swe05, p.21]. These limitations are critical for new information that needs to be processed by working memory before it can be stored in long-term memory.

Sweller refers to the working memory model Baddeley described in [Bad92]. In this model, the working memory is divided into a coordinating central executive and two subsystems: a visuospatial sketchpad for processing visual images, and the phonological loop for speech-based information. Sweller emphasizes that learning can be facilitated when both of these systems are used.

Schemas help to categorize and process new information and to overcome the limitations of working memory. If these schemas have not yet been acquired by the learner, they can also be provided as part of the instruction. Otherwise, it will result in a higher cognitive load.

According to Sweller, something is understood if all information relevant to it can be processed at the same time. As Sweller, van Merriënboer and Paas [SvMP98] state, schemas can contain complex content and relations. As those schemas that have already been integrated in long-term memory can be used in working memory as a single element, this allows for considerably more information to be processed in the working memory. For understanding to happen, instructional design has to make sure, with respect to the described models of working and long-term memory, either that there are not too many elements of new information to be processed or that the elements can be coordinated and categorized by schemas. These could already have been acquired by the learner or need to be provided by the instructional design.

Sweller [Swe05] states that the cognitive load theory distinguishes three categories of cognitive load:

1. **Extraneous cognitive load** is caused by design of learning material that does not consider cognitive structures. The aim of most work on the CLT is to reduce this kind of cognitive load.

2. **Intrinsic cognitive load** depends on the complexity of the information that is learned, especially how dependent different elements of information are on each other and whether they can be learned independently. Sweller calls this dependency *element interactivity.* When learning is considered in colloquial language, we often speak of information or relations with low element interactivity as "learning" and of those with high element interactivity as "understanding". A learning object with high element interactivity can not be understood separately from further elements or the relations between several elements.

3. **Germane cognitive load** refers to cognitive load necessary for schema construction and can be seen as "good" cognitive load in connection with the CLT. Germane cognitive load was added to the theory by Sweller, van Merriënboer and Paas in [SvMP98].

As an example where germane cognitive load is of interest, Sweller, van Merriënboer and Paas describe a situation where many worked examples (exemplary solutions to an exercise) are presented to facilitate learning for students, but the students do not use the worked examples. In this case, it can be useful to make some of the examples incomplete or ask questions on the examples. This increases germane cognitive load of the task, but as this is cognitive load used for schema construction, this can be seen as good effort.

As extraneous cognitive load is the category of cognitive load strongly related to the design of learning material, the following will concentrate mostly on this category.

Sweller states in [Swe05] that the quality of the instructional design, i.e. the learning material, might be unimportant for material that is easy to learn or, in other words, has a low element interactivity. He stresses the point that these design principles might only be critical for complex material. As pointed out in Section 2.1, a large body of anecdotal evidence by instructors indicates that courses on theoretical computer science are indeed seen as complex by students. Therefore the CLT should be a suitable choice for this content. Additionally, keeping in mind that mathematics is a closely related field, it is of interest that Sweller states in [Swe94] that mathematics seems to involve relatively high element interactivity.

There are several effects described in [Swe05] that were studied based on the cognitive load theory and give insight into important aspects of instructional design. The following gives an overview of several of them.

The *worked example* effect occurs when learners studying worked examples, including the solution learn more than learners solving the problem all by themselves. Searching for solutions and the already mentioned need for random steps and testing places too much load on working memory.

If attention has to be split between several sources of information, all relevant to understand the content, the *split-attention effect* happens. Integrating the different parts poses too much cognitive load and impedes learning. This can be solved by integrating the different parts into one, e.g. adding text to a diagram instead of placing it below or next to it.

The *modality effect* occurs in scenarios similar to the split-attention effect with several sources of relevant information. Here, the extraneous cognitive load is reduced by additionally presenting relevant verbal material and therefore making use of both subsystems of the working memory.

The *redundancy effect* also occurs when several sources of information are presented, but the difference to the two preceding effects is that not all information is relevant for understanding. Parts of the sources are relevant, and others only repeat information already presented. This effect enhances cognitive load. Removing the redundant parts eliminates this effect.

In [Swe94], Sweller states that instead of giving students a problem to solve all on their own, it reduces the cognitive load to give students partially completed problems to solve.

Many effects have been analyzed based on the CLT. Only those have been added here that fit the planned scenario of the Learning Units. For example, in [Swe94] Sweller describes the effect that goal-free problem solving reduces the cognitive load, in this case in the context of a mathematical exercise. The basic idea is, instead of asking students to calculate a certain angle of a geometric figure, to ask them to calculate as many angles as possible. As such tasks are time-consuming and harder to assess, they are not suitable for the Learning Units. Other effects that are not suitable as well are not discussed further.

The CLT has also been criticized in a number of publications. Three important points of criticism will be discussed here:

(1) Even though Sweller states in [Swe05] that there seems to be not enough evidence to assume a central executive in working memory any longer – in contrast to earlier publications (e.g. [Swe94]) –, other developments in research at the time, e.g. the episodic buffer proposed by Baddeley [Bad00], were not integrated into the cognitive load theory.

(2) Brünken, Plass and Leutner [BPL04] conclude that designing instructional material according to the CLT might lead to material with a low level of interest and therefore recommend a balance between interest and extraneous cognitive load.

(3) In [KSC06], Kirschner, Sweller and Clark criticize popular approaches of minimal guided instruction for not taking cognitive structures and research evidence into account. This is stated for many approaches like problem-based learning, inquiry learning, discovery learning, and experiential and constructivist learning. Kirschner, Sweller and Clark subsume all of them as being of minimal guidance. Based on the CLT they state that the heavy load caused by searching for explanations and solutions is unnecessary. These statements were criticized in several publications. Hmelo-Silver, Duncan and Chinn [HDC07] agree with the main points of Kirschner, Sweller and Clark considering unguided discovery learning. However, they disagree heavily with problem-based learning and inquiry learning being grouped with minimal guided approaches, as the former provide a large amount of scaffolding, i.e. an adaptable amount of guidance. The criticism of Schmidt, Loyens, van Gog and Paas in [SLvGP07] is similar, even though they concentrate only on the differences between minimally guided approaches and problem-based learning. They state that the underlying principles of problem-based learning are compatible with the cognitive structures and give examples relating to the CLT. Kuhn criticizes Kirschner, Sweller and Clark in [Kuh07] in a more general way for considering what the best instructional method may be, instead of considering which method fits which content. In [SKC07], Sweller, Kirschner and Clark reply explicitly to these three publications, emphasizing their original view that problem-based learning is mainly self-directed. They question the experimental design of the evidence for the effectiveness of problem-based learning. They state that none of the authors of the aforementioned papers addressed the problem that the aspect of discovery in the learning process necessary for such minimally guided approaches produces high cognitive load. Therefore, they strongly disagree with Kuhn.

Overall, the CLT gives many interesting insights into learning and design recommendations for instructional design. Empirical findings support the assumptions of this theory to a large extent. However, as the aforementioned criticism demonstrates, there is also room for improvement to the theory in general, and additionally, approaches to learning like problem-based learning exist, whose success can not be straightforwardly explained based on the theory.

3.1.2 Cognitive Theory of Multimedia Learning

As discussed in [May05], the CTML was, like the CLT, empirically investigated and refined by Mayer and other researchers. This section summarizes the theory and its implications for instructional design. It is compatible with the principles of the CLT. If not explicitly stated otherwise, the explanations in this section on the CTML will follow [May05] by Mayer.

According to the CTML, students create mental representations of what they learn from words and pictures. The underlying assumption, which was empirically confirmed, is that students can learn better from (corresponding) words and pictures than from words alone. Mayer calls this the *multimedia principle.* He researched under which conditions instruction with multimedia leads to meaningful learning.

Like the CLT, the CTML assumes an information processing system with two channels – one for visual and one for verbal processing, as described by Baddeley in [Bad92]. Both of these channels have a limited capacity. Beyond the focus of the CLT, Mayer emphasizes the importance of active learning, i.e. the learner must carry out specific processes during learning. These processes are:

- The selection of relevant words from presented text (spoken or heard) and relevant images from presented illustrations,
- the organization of the words into a coherent verbal and the images into a coherent pictorial representation and
- the integration of these representations in combination with existing knowledge.

He defines active learning as occuring "...when a learner applies cognitive processes to incoming material" [May05, p.36].

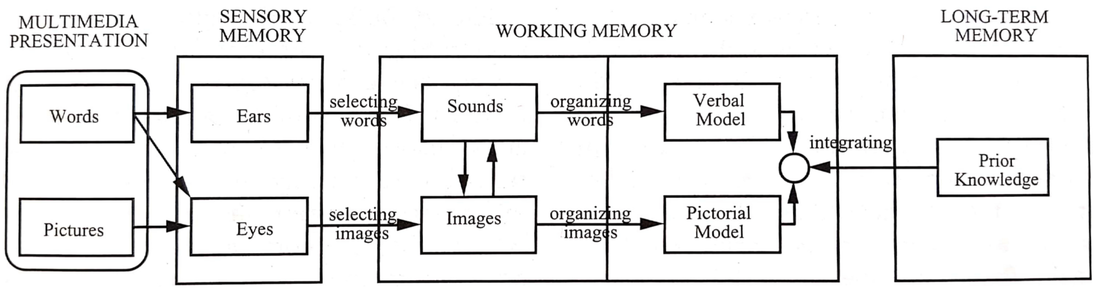


Figure 3.1: Learning processes according to the CTML. [May05]

For these processes, it is relevant to choose which words or images should be selected and what connections should be built. Mayer emphasizes the importance of metacognitive strategies for the usage of the cognitive resources to enable and control this. These strategies are a fundamental part of the brain's central executive.

Learning, according to the CTML, is demonstrated graphically in Figure 3.1. Words and pictures are perceived via sensory memory. Then the relevant parts are selected.

Both sounds and images are organized to a verbal or, respectively, pictorial model and integrated by cognitive effort in combination with prior knowledge.

Afterwards, this integrated information can be processed to long-term memory. All of the aforementioned processes occur iteratively, and according to the CTML, instructional methods that support these processes thereby lead to meaningful learning. An important point is that such meaningful learning is most likely when the learner has matching pictorial and verbal representations in their working memory. This corresponds with the idea that words and pictures are preferable to words alone as instructional material.

Several effects were studied based on the CTML. In [May03], Mayer describes the following three effects that are relevant for the design of the Learning Units:

The *coherence effect* demonstrates that instructional material should not include interesting yet irrelevant material on the content, as this distracts the learner.

Similar to the *split-attention effect* described for the CLT, Mayer found a *spatial contiguity effect* when images and corresponding text were too far apart from each other, both with printed text and via computers. Keeping text long enough in working memory to be integrated with the image (or vice versa) impeded the learning process.

Furthermore, a *personalization effect* was found, where meaningful learning was more likely to occur when text was formulated in a conversational rather than a formal style. Mayer assumes that the reason for this effect is that humans are more likely to engage stronger in the processing when they feel as if they are having a conversation.

In [MM02], Mayer and Moreno state other interesting effects concerning the CTML and animation:

The *modality principle* states that learning is facilitated by using animation in combination with narration rather than by animation in combination with on-screen text. The latter could exceed the capacity of the visual channel, whereas the former will not.

Based on a similar idea, the *redundancy principle* states that using animation and narration is preferable to using animation, narration and on-screen text at the same time. This, again, could otherwise exceed the capacity of the visual channel.

As with the CLT, Brünken, Plass and Leutner [BPL04] criticized the CTML for its use on instructional design that could lead to material of low interest. They possibly did not fully take into account that the CTML emphasizes student engagement with its view on active learning, which should make it clear that material also needs to be interesting. Rey [Rey19] criticizes the absence of motivational and emotional processes and the heavy focus on working memory in the theory.

Overall, the CTML is empirically well-grounded (see e.g. [May03], [May05]) and leads to several further design recommendations, especially where the participation of the learner is concerned. Still, an extension was proposed, which will be presented in the following.

3.1.3 Cognitive-Affective Theory of Learning with Media

The CATLM extends the CTML in a few relevant aspects. If not explicitly stated otherwise, the explanations in this section on the CATLM will follow [Mor05] by Moreno.

The CATLM assumes several principles that have already been used by the CLT and the CTML:

- Limited capacity in working memory, which is in line with the CLT and the CTML.
- Knowledge being encoded in two representations, either as verbal or as nonverbal.
- The possibility that schemas can be processed automatically after sufficient practice.
- Metacognitive factors increasing or decreasing the learner's cognitive engagement.
- Active conscious processing being necessary for meaningful learning.

Furthermore, the CATLM adds or expands several assumptions:

- Incoming information is processed on different channels. The difference here is that the CATLM also assumes a tactile channel for information that can be felt. In [MM07], Moreno and Mayer additionally add a gustatory and olfactory channel.
- Long-term memory has immense capacity. In [MM07], Moreno and Mayer describe long-term memory further as consisting of two parts – one for past experiences and one for domain knowledge.
- Motivational factors increase or decrease the cognitive engagement of the learner.
- Individual differences affect learning, including prior knowledge or cognitive styles (which will be called learning styles in the next section). While prior knowledge was already part of the CTML, adding learning styles is a new concept in the CATLM.

The processes of learning, according to the CATLM, are described in Figure 3.2. The structure is very similar to that of the CTML. As mentioned before, the number of channels for sensory information increased. These channels process incoming information, which is selected by the attention of the learner and held in working memory. In working memory, the information is organized, possibly linked to knowledge from long-term memory and stored in long-term memory. The process is mediated by factors of motivation and metacognition.

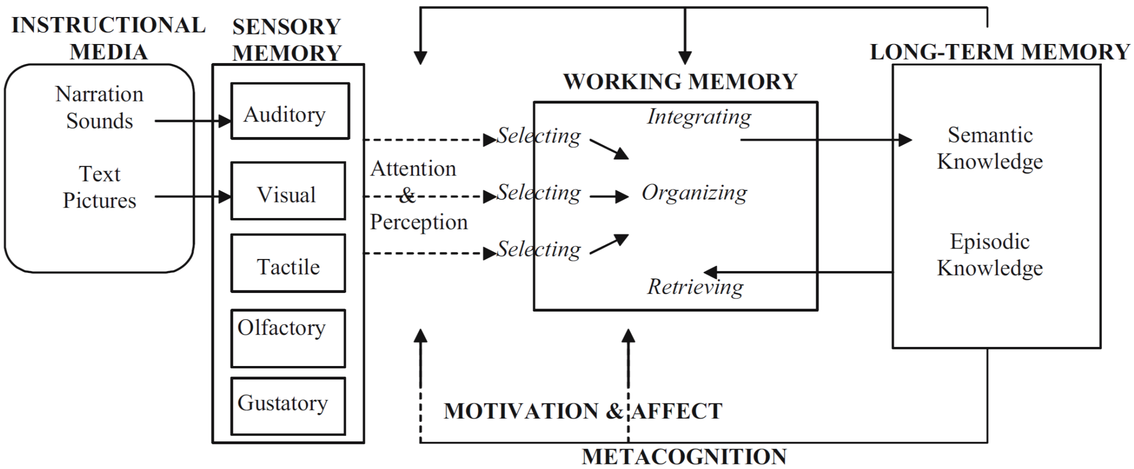


Figure 3.2: Learning processes according to the CATLM. [MM07]

A further interesting aspect for this dissertation is that in [MM07] Moreno and Mayer stress the advantages of interactivity in accord with the CATLM. They define interactivity as "responsiveness to the learner's action during learning" [MM07, p.310]. They discuss five common types of interactivity:

1. Dialoguing – getting feedback from the system.
2. Controlling – changing the pace of explanations or the order of viewing the content.
3. Manipulating – reacting of the system to user input.
4. Searching – querying the system via search.
5. Navigating – making choices which content to view.

Except for searching, all of these types will be integrated into the Learning Units to a certain level.

As with the CLT and the CTML, design principles have been discussed for the CATLM. In [Mor05], Moreno discusses only design principles that already existed for the CTML. In [MM07], Moreno and Mayer discuss further principles, three of which will be presented here:

The *feedback principle* states that explanatory feedback, where the correct solution or steps towards it are explained, is better than corrective feedback. This term stands for solely stating whether the answer was correct or incorrect. Explanatory feedback reduces extraneous processing and the following reflection, according to Moreno and Mayer, is in line with the metacognitive mediation assumptions.

The *pacing principle* states that students learn better when they are actively in control of the pace and can pause their learning or, for example, repeat an explanation. By doing this, they are able to process smaller chunks of information and therefore learn better.

In the *pretraining principle*, Moreno and Mayer found out that when doing pretraining with the students to activate or provide prior knowledge, meaningful learning was more likely to occur.

It can be criticized that the CATLM is not easily applicable in all design recommendations. One example is the *reflection principle* presented by Moreno and Mayer in [MM07]. It states that it is advantageous to ask students to reflect upon correct answers, which is not easy to implement in a system where there is no instructor for pacing such an approach. Other criticism by Rey in [Rey19] states that the CATLM does not provide proper design recommendations on the aspects concerning motivation and metacognition.

Overall, the CATLM is a useful expansion to the CTML, especially when the critique of the CTML is taken into account. It leads to several design recommendations but also to the general principle of developing motivating content.

3.2 Learning Styles

This section will present the Felder-Silverman model of learning styles. As mentioned for the CATLM, different learning styles of students affect learning. Therefore the model will be used to generate further design recommendations. The idea hereby is not to tailor the Learning Units to a specific learning style or to adapt the system, but rather to include learning possibilities for students of different cognitive preferences to be chosen by the learner (consciously or unconsciously). The theory of learning styles by Felder and Silverman was first published in [FS88] and later made available online in an extended version [FS02], which the explanations in this section will follow, if not explicitly stated otherwise. The corresponding questionnaire “index of learning styles” (ILS) to test the current learning styles of participants will be presented in more detail in Section 5.4. It is available online[1]. The model was chosen as it has been widely used, was validated, and because the corresponding questionnaire is free to use for research. In [FS05b], Felder and Spurlin summarize existing studies on the validity and reliability of the ILS questionnaire, concluding that it is both valid and reliable.

[1] `https://www.webtools.ncsu.edu/learningstyles/`

It is essential to distinguish learning styles from the so-called learning types according to Vester, where different channels of perception allow for differences in learning possibilities [Loo01]. Learning styles describe mere preferences of the learner on different dimensions. These styles are also subject to change over time. The basic idea of the model is that instructors that include both poles of these dimensions improve the environment for the learners.

In the re-published version, one dimension was renamed from visual/auditory to visual/verbal to simplify classifying written words. The only other change was dropping the inductive/deductive dimension of the model. Induction is defined as inferring principles and deduction as deducing consequences. The latter is the typical teaching style, according to Felder. As Felder was cautious against instructors justifying a deductive teaching style with the results of the ILS, the dimension was dropped.

The following dimensions are part of the model:

- Active and reflective learners
- Sensing and intuitive learners
- Visual and verbal learners
- Sequential and global learners

Active learners prefer active experimentation, whereas reflective learners tend to reflective observation. Active learners therefore correspond with extrovert actions. Here, Felder and Silverman include actions like discussing, testing or explaining. Reflective learners prefer time for introspection and reflecting. Felder and Silverman state that active student participation is suitable for both reflective and active learners.

Sensing learners learn more easily with facts, whereas intuitive learners tend to concepts. Therefore, sensing learners prefer data and experimentation and working with standard methods. An intuitive learner prefers to work with theories, principles and more abstract concepts. They like innovation and working on complications. Felder and Silverman state that the majority of engineering students seem to be sensing learners, whereas the common teaching style emphasizes concepts and therefore favors intuitive learners.

Visual learners prefer pictures, plots or animations for content presentation, whereas verbal learners prefer written text or spoken words.

Sequential learners learn best when content is presented as a sequence, where the next part builds on the previous one. This is the typical structure of school and university courses. Global learners want to have access to the big picture of the content or the area from the beginning and choose their own order, learning in a non-linear fashion.

It is important to note here that those preferences are the extremes of those four dimensions. The ILS results show tendencies of the learner to one side or the other. Results on the border between the two are also possible.

Academic views on learning styles are mixed. In a meta-analysis of 29 studies in Turkey in [Kan16], Kanadli found that designing a learning environment according to learning styles had a large impact. Dunn et al. [DGO+95] conducted a meta-analysis of 42 studies and came to the conclusion that their Dunn and Dunn learning style model increased academic achievement. Contrary to these results, studies that reported small effects or none at all can be found as well. In their extensive report on learning styles, Coffield et al. [CMHE04] discuss many problems with this research area, especially the diversity of the many existing approaches and resulting recommendations. In their examination of experiments, Pashler et al. [PMRB08] also do not see enough evidence to support the use of learning styles and matching presentation with the learner's preference. Husmann and O'Loughlin [HO19] found no correlation of learning style and achievement in a recent study.

As the learning style model is used only for general design recommendations in this dissertation and not to tailor the approach to specific learning styles, these heavily mixed findings are not seen as an issue.

3.3 Existing Multimedia Solutions for Theoretical Computer Science

In this section, a meta-analysis on the e-learning approaches in the area of theoretical computer science that were already presented in Section 2.1.3 is conducted. These approaches are complemented by selected studies and overviews of the creation of e-learning platforms in general, or on topics related to theoretical computer science. This section will answer the Preliminary Question 2: "Which criteria for multimedia-based learning existed in previous studies on theoretical computer science and what effects were reported?" It is important to emphasize that these criteria are not intended to rate approaches or platforms considering e-learning, as approaches heavily depend on the given setting and several other factors. The criteria are intended to give design recommendations, formulated as questions for instructors to use in the process of planning and developing an e-learning approach. In this section, at first the criteria will be presented, followed by the analysis considering which aspects of these criteria originated from which source. In the following, platform is used as a generic term referring to whatever online elements an approach includes.

The meta-analysis resulted in the following criteria:

1. *What is appropriate for this setting?*

   (a) *What is the target group?* **(target group)**
   Target groups may differ strongly in their previous knowledge, their abilities on self-regulation, or their abilities to use a computer. Therefore, it is important to carefully consider the target group for possibilities in planning an approach and also whether this target group is assumed to be heterogeneous or homogeneous. For example, a target group of students that is completely equipped with modern smartphones might have other possibilities than a group of retirees where such equipment differs considerably.

   (b) *How much effort is intended?* **(intended effort)**
   As introducing any approach involving e-learning creates additional load for instructors, it needs to be considered how much effort the instructor is planning to dedicate to this approach. How much effort will be necessary to create the corresponding material? How much effort will be necessary to maintain the material? The planned time dedicated to the approach should cover these efforts.

   (c) *Which type of multimedia-based learning will be used?* **(type)**
   Depending on the setting, ideas for opening a platform for other courses or universities or the public might be plausible. Different basic approaches can be chosen. Examples are Massive Open Online Courses (MOOCs), which are fully online and capable of covering large numbers of students. Blended approaches usually combine in-class and online elements. The in-class elements usually allow for a smaller number of students in such courses. Supplementing a course with e-learning without changing the course as is done in this dissertation is therefore a blended approach.

   (d) *How much variation will be integrated?* **(variation)**
   As students may have different personal preferences considering the perception of different online elements, integrating variation may be useful to reach larger parts of the target group.

(e) *What elements will be used?* **(used elements)**
What are the specific elements that fit this setting? Is there a need for videos, text, sounds, single- or multiple-choice questions, ...?

(f) *What further technical aspects should be integrated?* **(technical additions)**
Are there plans to integrate particular technical aspects? One typical example is adaptivity, for example according to learning styles or learner's progress.

(g) *Which platforms are appropriate?* **(platform)**
Based on the previous questions, a platform should be chosen that fits all the needs and covers possibilities to integrate all the considered elements and technical variations, is able to cope with the number of estimated users and can be used with reasonable effort.

2. *What is appropriate regarding content?*

(a) *Are online elements to be aligned with offline elements?* **(aligned content)**
Aligning the online elements to a course can be useful, depending on the setting. Alternatives are expanding study materials for high performing students, or information for all students that can not be covered in the course but is still part of the curriculum. It is crucial to decide on this aspect when planning such an approach.

(b) *Are choices and intended learning outcomes aligned?* **(aligned outcomes)**
In the process of developing an approach, it is necessary to regularly question whether the design decisions are in line with the intended learning outcomes. Considering the extra effort for an instructor to correct or rework such an approach in particular, this is an aspect with substantial impact.

(c) *What is necessary for this content area?* **(content area features)**
Many content areas have special features that are necessary for e-learning approaches. Theoretical computer science uses many formulas and often proofs in explanations. Formulas are also necessary for several other disciplines (e.g. chemistry, physics, mathematics) but often using different characters. A programming unit might need a programming or testing environment, while a physics unit might need visualization of specific forces. What these special features are and how to implement them in a useful way is also an important part of the development.

3. *Is there attention to cognitive ergonomics?* **(cognitive ergonomics)**
Cognitive ergonomics is a relevant aspect of platform design. This discipline is concerned with how design can be implemented in a user-friendly way. For well-known platforms, this aspect may have already been studied. In these cases, the instructor only needs to take those results into account. In all other cases, this must be considered even more carefully. A finished platform that is too hard to use for the students due to its design might cause frustration.

4. *What kind of interaction is included?*

   (a) *What interaction with people is possible?* **(interaction with people)**
   Does the approach contain a possibility that students interact with other students or instructors? Possibilities are, e.g., discussion boards, wiki entries, chats or social interactions like commenting or sharing what another student wrote.

   (b) *What interaction with the platform is possible?* **(platform interaction)**
   A vast number of possibilities of interaction with platforms exists. It is necessary to choose which of these possibilities are to be included in an approach. This starts with the navigation and possibilities to personalize the learning experience, e.g. by choosing designs, ordering of content or difficulty. Several different question types are possible, including single-choice, multiple-choice, filling gaps, puzzles, open questions where text can be entered freely, and many more. Feedback can additionally be involved by giving hints or reacting on user input, e.g. on answered questions.

5. *How are students assessed?* **(student assessment)**
In this case, assessment refers to students answering questions in class or receiving grades, course points or something similar for handing solutions in or exams. This is in contrast to situations where students answer questions in the process of learning with a platform to get feedback. This would, in terms of the categories presented in this chapter, be categorized as platform interaction. Assessment related to grades or passing a course might be engaging for the students.

6. *How is the platform evaluated?* **(platform evaluation)**
In evaluating a platform while it is being developed (formative evaluation) and additionally when it is finished or already in use (summative evaluation), the instructor can get relevant feedback where problems occur for students. Different ways of evaluation can be considered, beyond solely differing in terms of when a platform is

evaluated. Another point of view is what the target variable of the evaluation is, e.g. concerning learning outcomes, motivation, student satisfaction and further possible variables.

3.3.1 General Criteria for E-Learning

For this first part of the analysis, studies were used that present a general overview of criteria for settings with e-learning. For this, it was deliberately chosen to use studies with different approaches on the subject to grasp important criteria for the design of e-learning in different settings.

Nortvig, Petersen and Balle [NPB18] conducted a literature review to analyze which factors influence the use of e-learning and blended learning. The researchers analyzed and categorized 44 articles involving e-learning approaches (independent of the discipline). Their main conclusion in this analysis is that it is important to look at factors beyond the pure choice of a format (like e-learning or blended learning) to create a successful approach. For each format, successful and unsuccessful approaches could be found under differing conditions. They discuss possibilities of interaction between students and also between students and instructors to create and maintain a learning community and foster learning (**interaction with people**). An essential aspect of good course design, according to this review, is relating online and offline activities (**aligned content**). Another aspect they emphasize is variation in online as well as offline activities (**variation**). Additionally, Nortvig, Petersen and Balle stated that it is important to create connections to practice-related activities, which was not integrated into the criteria, as relating to practical aspects heavily depends on the content area in question and is not of interest for the scope of this work.

Blass and Davis [BD03] propose criteria for e-learning development with learner-orientation and effectiveness as goals. They discuss the enormous amount of effort it takes to create good e-learning material (**intended effort**). An important part of their analysis is the idea of appropriateness of an approach. In the criteria above, the question is formulated, whether the design choices are in line with the intended learning outcomes. Blass and Davis formulate this even more broadly, questioning whether the learning outcomes are even suitable for an e-learning approach. For example, practical skills might be necessary that can not be adequately taught in a digital way, or the material might otherwise in itself not be appropriate to be learned from distance. Later in the paper they also discuss the relationship between learning outcomes and design decisions for an e-learning experience (**aligned outcomes**). The discussion on appropriateness also includes whether an appropriate platform for the approach exists (**platform**) and which elements are to be used (**used elements**). Even though parts of the analysis in the paper are based on a rather economical view, considering the proper market for the e-learning approach, Blass and Davis discuss the students' situation and possible differences in skill from a relevant point of view (**target group**). Blass and Davis point out how important cognitive ergonomics are for the development of good e-learning (**cognitive ergonomics**). A stimulating presentation that does not distract students and fits the setting is important. Blass and Davis emphasize the importance of integrating interaction between students and faculty as well as in-between students (**interaction with people**), but also to allow for interaction with a platform beyond, e.g. looking at lecture slides (**platform interaction**). Interestingly, they discuss the assessment of students in different forms (e.g. milestones, tests, and more) as a form of reinforcement, helping learners to engage with an e-learning approach (**student assessment**). Finally, Blass and Davis discuss several forms to evaluate a platform on different aspects (**platform evaluation**).

Graf and List [GL05] analyzed nine different open source e-learning platforms for their strengths and weaknesses using a qualitative weight and sum approach. An important factor for them was the possibility for automatic adaptation in a platform, where the platform changes based on the users' progression (**technical additions**). The result of this analysis is that Moodle outperforms the other platforms in most categories. They emphasize its good usability especially (**cognitive ergonomics**). In the course of evaluating the platforms, they list the properties important to them, e.g. communication tools like forums or chats (**platform interaction**) and other aspects that were not explicitly integrated into the list above, like the management of user data and security considerations.

Shee and Wang [SW08] proposed a multi-criteria methodology to evaluate e-learning approaches and conducted a study on learners' perceptions of design criteria among 276 students. Their proposed model for evaluation contains four dimensions. The first dimension is the learner interface, containing criteria like ease of use, understanding and user-friendliness (**cognitive ergonomics**). The second dimension, learning community, contains criteria like how easy it is to discuss and work with other learners and teachers on the platform (**interaction with people**). The third dimension, system content, contains criteria on how good and up-to-date the content is. Whether updating content is necessary, and whether there is sufficient content (in terms of quality and quantity) can be seen as an aspect of aligning the content with learning outcomes (**aligned outcomes**).

The fourth dimension with the somewhat unexpected title "personalization" contains criteria on whether learners can inform themselves about their progress on the platform and record their performance. These criteria would rather be expected in a dimension on how the system interacts with its users (**platform interaction**). The main result of the corresponding study is that the user interface (the first dimension) is seen as the most important dimension.

3.3.2 Criteria in Approaches on Theoretical Computer Science

After the analysis of general criteria in the previous section, the following will consider several approaches where theoretical computer science was combined with e-learning. The perspective here is which aspects of the criteria above appear in each of these approaches. Additionally, where such information is reported, results on effectiveness and success factors will be examined. The order of the approaches follows Section 2.1.3.

With Tarski's World [BE93a] and Turing's World [BE93b], Barwise and Etchemendy published two packages combining hands-on software with books for students to learn first-order logic or Turing machines. The books contained explanations on the content and examples to be done with the respective software. Later, an enhanced version of Tarski's World was republished alongside further software (e.g. programs for checking proofs or truth tables) in Language, Proof and Logic [BEA+02]. Tarski's World was updated and published again years later by Barker-Plummer, Barwise and Etchemendy [BBE07]. In [BE98], Barwise and Etchemendy describe the two original software packages extensively, illustrating the interactive nature of the programs (**platform interaction**). In Tarski's World, a step-wise game helps the learner to get feedback, if a solution was incorrect. In [BEA+02], Barwise and Etchemendy describe how, when the software is used in a course, solutions can be submitted online to a grading platform, and results are sent to the course instructor (**student assessment**). Apart from Barwise and Etchemendy calling the software successful in [BE98], and the publishing of several versions of the software over the years which can be interpreted as the software being successful, no results on effectiveness or usage were reported.

Devedzic, Debenham and Popovic [DJD00] describe the FLUTE system. FLUTE is an intelligent tutoring system on FLAT topics. The system controls the learning progress of the student, choosing content, examples and exercises relative to their current progress, even offering hints and suggestions (**platform interaction**). When a difficulty level is mastered, the system allows the student to work on more complex exercises or content.

FLUTE contains different modes for learning and examination. The current progress is saved in a student model. The student can see but not alter the values of this model other than by working on the platform. The users of FLUTE are expected to be grown-up computer engineering students (**target group**). As an evaluation, Devedzic, Debenham and Popovic compare the FLUTE system to other intelligent tutoring systems. Main results are that FLUTE has advantages due to being systematically designed, its refined student model and its levels of assessment (**platform evaluation**).

Pillay and Naidoo [PN06] also describe an aspect of a planned intelligent tutoring system. The focus of the paper is the possibility to automatically generate automata as solutions for the learner. The main idea is that the user creates an automaton to work on an exercise, and that the system is able to generate the solution for him in an adaptive way (**technical additions**). This approach was created to allow for more individualized tuition and giving feedback (**platform interaction**). The system was tested with 15 languages. In all cases, the automatically generated solutions were equivalent to solutions created by humans (**platform evaluation**).

Tscherter [Tsc04] developed Exorciser. In this software, exercises for the theory of computation can be generated, and feedback is given to help the students find their mistakes (**platform interaction**). Considering the chosen area of the approach, Tscherter discusses the problem that such highly interactive approaches are only possible for a small number of areas. He states several guidelines for his system: exercises are meant to be challenging, feedback should be provided, the student should be in control of the process and students should be given the solution, if they request it. Additionally, he proposes that the system needs to be highly usable (**cognitive ergonomics**). The usability was tested with a survey amongst students who were directly asked whether they found it useful. The system was evaluated in a comparative study with 195 students. For two of the four exercises used in the survey, Tscherter found a significant difference towards those students that had used Exorciser (**platform evaluation**).

Grinder et al. [GKL+02] and Cogliati et al. [CGG+05] proposed a hypertextbook for FLAT. It contained content with hyperlinks to follow in-between topics and applets to test the newly gained knowledge (**platform interaction**). According to [CGG+05], several design guidelines have been used in the development of the hypertextbook: platform independence, incorporation of different levels of difficulty in the material (**variation**), and a general ease to use and extend it.

Some approaches are more strongly based on a particular university course and use e-learning without using a platform in the common sense of the word. Still, the same criteria as above will be applied:

Berque, Johnson and Jovanovic [BJJ01] discuss a course on theory of computation taught with pen-based computers and an electronic whiteboard linked to these pen-based computers. The students were to take notes and solve exercises in class on their pen-based computers (**platform interaction**). The main part of the interaction, however, was still face-to-face. The teacher could explain content using the electronic whiteboard and then send his notes directly onto the students' pen-based computers. This approach was strongly aligned to the course (**aligned content**) and to the intended learning outcomes (**aligned outcomes**). The approach was seen as a success but evaluated only by asking the students whether they preferred it to the traditional teaching method and whether they believed their level of attention was higher (**platform evaluation**).

Brauer et al. [BHKS03] embedded the content of their course in an adventure story and additionally used the tool Grail. This approach was undertaken for a second-year undergraduate course on topics of theoretical computer science (**target group**). The story was used as a setting to engage students and motivate them. The additional tool was used for hands-on work on automata and regular languages (**platform interaction**). This approach was also strongly aligned to the course (**aligned content**) and to the intended learning outcomes (**aligned outcomes**). The approach was evaluated only informally and by the general lecture evaluation, both of which were positive.

Rohde and Thomas [RT03] present a system for lectures that is able to capture voice and annotations in combination with slides and an additional tool for exercises. The setting included three courses on theoretical computer science, the approach and the courses were strongly aligned (**aligned content**). Rohde and Thomas extensively discuss the vast effort that is necessary to create and maintain an e-learning approach and their aim to reduce this effort (**effort**). As much as possible, existing elements were integrated in the approach to reduce this effort. They also state how important the use of formulas in the area of theoretical computer science is (**content area features**). The resulting annotated slides with the lecturer's captured voice have a low level of interaction, similar to watching a video. Students can answer exercises with the additionally developed tool (**platform interaction**). The effectiveness of the approach was tested in all three courses using questionnaires, evaluated by descriptive statistics. The results are only described briefly but seem to be positive overall.

Nestmann and Wilhelm [NW14] describe another approach with low interactivity. Screencasts were used as a supplement for the FLAT course at Technische Universität Berlin. The screencasts and the corresponding course were strongly aligned (**aligned content**). They also discuss the huge effort in developing e-learning content (**effort**). At several points, they also discuss the usage of formulas in the area of this FLAT course (**content area features**). Evaluation results are not discussed in the article.

In [Rei03], Reichert presents the programming environments Kara, TuringKara, Multikara and JavaKara. They are mainly targeted at schools but used in some universities as well (**target group**). Developing these environments was part of the work (**platform**). In general, the user of Kara controls a ladybug through a two-dimensional environment via transition rules. The environments consist mainly of trees, blocking the path of the ladybug. The environments are concerned with giving an introduction to programming (Kara), the theory of computation (TuringKara), basics of concurrency (Multikara) and a transition from Kara to Java programming (JavaKara). The contents were not aligned to a specific course (**aligned content**). According to Reichert, the intentions of the approach were met. Particularly of interest was conveying programming basics in a strongly visual way (**aligned outcomes**). For TuringKara, the user does not control the ladybug but the head of a two-dimensional Turing machine through a world of zeros, ones, and further alphabet symbols (**content area features**). Special attention was given to developing a good user interface and visualization (**cognitive ergonomics**). Students could program the ladybug (or the head of the Turing machine), solve exercises and construct individual scenarios (**platform interaction**). The Kara environments were used extensively but only formally evaluated in very brief surveys, where students could assess whether their learning benefitted from the environments and how they experienced the user interface. The results on these surveys were very good on both aspects (**platform evaluation**).

InfoTraffic [Arn07] is presented by Arnold and comprises three interactive learning environments on propositional logic (LogicTraffic), queuing theory (QueueTraffic) and Markov chains (DynaTraffic). Similar to Kara, the learning environments were developed as part of the work (**platform**). In LogicTraffic, a given intersection is formalized by variables representing lanes. The goal for the user is to find a formula that operates a traffic light in a way that crashes are avoided. Users work with a truth table, can get hints and check their current solution. In QueueTraffic, users work on traffic jams. The parameters of this round-based simulation can be altered by the user. DynaTraffic offers pre-defined traffic situations, expressed as Markov chains. The user can modify transition probabilities or the respective car distribution and analyze the situation. All three environments offer a high degree of interactivity (**platform interaction**). The environments were not evaluated in a study but insights from their usage and positive anecdotal evidence were summarized (**platform evaluation**).

Analyzing the two MOOCs already briefly presented in Section 2.1.3, it is also interesting to see which elements were chosen by their creators. The MOOC on the platform Udacity [Uda] uses videos for the content, interactive quizzes to master each topic (**platform interaction**, **student assessment**) and offers a discussion board for exchange in-between students (**interaction with people**). The MOOC at the University of Stanford [Ull] also uses videos for the content and interactive quizzes. Additionally, homework and exams have to be handed in for course completion (**student assessment**).

Overall, it has to be concluded that results on effects could hardly be found in the presented articles.

3.3.3 Criteria in Selected Further Approaches

In this part of the analysis, three more approaches will be looked into that were chosen to widen the perspective. As mathematics is closely related to theoretical computer science in terms of the use of formulas, two of the approaches consider e-learning in mathematics.

Breslow et al. [BPD+13] discuss the first MOOC at the platform edX[2] on circuits and electronics. The platform was created inter alia by the Massachusetts Institute of Technology (MIT) and Harvard University. In this first MOOC, 155,000 people enrolled and 7100 passed in its first run. Content was presented via video and an electronic textbook (**used elements**), and students were able to work on exercises via the platform (**platform interaction**). They could interact with other students via a discussion board or a wiki (**interaction with people**) and had to hand in several assignments (**student assessment**).

Dazaa, Makriyannisa and Riera [DMR13] describe a MOOC on mathematics. The intention for creating this MOOC was to bridge the knowledge gap that appeared between high school and university for many students due to their heterogeneous backgrounds. Students could learn with videos and use quizzes where they got feedback on wrong answers (**platform interaction**). Students could discuss issues with other students on a discussion board (**interaction with people**). Additionally, weekly challenges were given to the students as a motivational tool (**student assessment**). At the beginning, the course

[2] `https://www.edx.org/`

had 2130 students enrolled (later even 2472), and 198 replied on a survey created by the instructors (**platform evaluation**). 1580 students actually used the course in some way. Overall, the dropout rate was at 80 percent.

In [Pae05], Paehler discusses the development of the multimedia-based mathematics instruction for engineers (MUMIE)[3] platform for highly interactive learning of mathematics, often with explanations based on text or video, but overall with a focus on generating examples and giving feedback on them (**platform interaction**). Paehler extensively describes the generation of mathematical applets and interactive exercises for the MUMIE platform. He also mentions several times how formulas were integrated in the approach (**content area features**). Paehler also describes combinations of further e-learning elements with these applets to help students learn, alongside first small positive evaluations. In [VDDvK12], Vuik et al. discuss an application of the MUMIE platform at Delft University of Technology. This was evaluated based on surveys (**platform evaluation**). The answers of the students indicated that a large body of them saw the platform as helpful and recommendable, but also a small percentage of students that strongly disagreed to this. This is interesting considering the different preferences of students.

3.4 Related Studies

After this analysis considering the criteria for e-learning approaches, this section will take a second look at the studies that have already been presented in Section 2.1.5. The focus of this consideration will be which abstract aspects and concrete topics the studies recommend for improvement based on their results.

Armoni and Gal-Ezer [AG06] stress the general importance of abstraction, here explicitly on the notion of reduction. Reduction is used to relate different problems to each other by transformation. The preliminary study on 63 students in a FLAT course conducted by Armoni and Gal-Ezer found a lack of abilities in students to use reduction compared to the researchers' expectations.

Pillay [Pil10] conducted a study in a FLAT course to work out the learning difficulties of the students. One major result was that the students had problems to conceptualize proofs. Pillay names the pumping lemma as an example. Additionally, she found a lack of problem solving skills. Examples here are converting a non-deterministic finite automaton (NFA) to a deterministic finite automaton (DFA), creating regular expressions for languages, and creating regular expressions for given NFAs. Many students had problems to

[3] `https://www.mumie.net/`

construct regular and context-free grammars and simplify them. Additionally, students had problems in constructing Mealy machines, Moore machines, pushdown automata and Turing machines.

Knobelsdorf and Frede [KF16] observed three groups of students working on their homework assignment in a qualitative study on a theory of computation course. They found a lack of work proficiency in these groups, especially considering the use of mathematical notation. Problems with managing the different working phases and ordering these phases usefully could be observed.

Frede and Knobelsdorf [FK18] conducted a quantitative study on the homework and exam results of students in the FLAT course at Technische Universität Berlin. They analyzed this large body of data in an exploratory data analysis. The first set of homework in the course was submitted by 571 students. Frede and Knobelsdorf found that students particularly had problems with creating formal proofs, especially with the pumping lemma. Additionally, they found problems in a number of areas, e.g. logic, the use of sets, equivalence classes, grammars and the usage of the Myhill-Nerode relation.

3.5 Resulting Design Recommendations

In this chapter, many aspects that will be used for the design of the Learning Units have been discussed. In the following section, the main points for the three learning theories, the learning styles and the results of the meta-analysis on existing work will be summarized.

(CLT) The Learning Units will

- use worked examples,
- integrate images and corresponding text (*split-attention effect*),
- avoid redundant text,
- use partially completed problems,
- use (in videos) voice and images or written content to make use of both subsystems of working memory (*modality effect*),
- give clear guidance for problem-solving to avoid students feeling need for random steps,
- present a small number of elements at a time,

- facilitate schema acquisition by integrating explanations on connections between content and content structure.

(CTML) The Learning Units will

- support active processing,
- combine words and pictures (*multimedia effect*),
- exclude material irrelevant to the learning outcomes (*coherence effect*),
- use a conversational style (*personalization effect*),
- avoid the combination of animation and on-screen text (*modality principle*) and also in the addition of narration (*redundancy principle*).

(CATLM) The Learning Units will

- use explanatory feedback (*feedback principle*),
- give students control of the learning pace (*pacing principle*),
- use pretraining to activate prior knowledge,
- consider individual differences of students,
- integrate interactivity.

(Learning Styles) The Learning Units will

- improve motivation regarding the content,
- provide both theories and facts, if possible,
- balance understanding and exercises,
- provide illustrations,
- provide opportunities for activity.

(Existing Solutions) The meta-analysis of existing solutions resulted in the synthesis of several essential aspects that have to be taken into consideration when creating an e-learning approach. Both the target group and the manageable effort considering creation and maintenance both have to be considered for choosing the used type of e-learning. Variation can be important for different preferences people have when learning. Based on the decisions on variation and type, the elements of the approach can be chosen. Some approaches add further technical aspects like adaptivity to the learner's preferences. Based on all these former aspects, a platform can be chosen or developed that offers these options. The instructor has to choose whether the online elements are intertwined with elements of an actual course, depending on the setting. Additionally, it is necessary to check whether the learning outcomes fit the approach. Otherwise, it needs to be reworked. Some content areas have special symbols or other specialities that need to be covered. In the analysis, for example, formulas were brought up by several articles as a speciality for theoretical computer science. The chosen or developed platform needs to take cognitive ergonomics into account so that users are not distracted or demotivated by design features inherent to the platform. It is necessary to choose what interactions with people and the platform are to be included. In particular, means of interacting with a platform can heavily affect the effort to create an approach. Another relevant decision is whether the students are to be assessed in some way beyond self-testing, e.g. relevant to course grades. In development and application, it is necessary to evaluate such an approach.

(Related Studies) In the related studies, several abstract concepts and techniques have been pointed out that students have problems with. Abstraction and conceptualizing proofs have been found as problem areas. Another problem area was the ability for problem-solving and a general lack of work proficiency, especially where clear working phases on an assignment are considered. Students had problems to use mathematical notation properly.

Specific topics where students had problems in the studies included the use of the pumping lemma, converting NFAs to DFAs, creating regular expressions as well as regular and context-free grammars, and simplifying grammars. Creating automata was a problem for Mealy machines, Moore machines, pushdown automata and Turing machines. The use of logic, sets, equivalence classes, and the proper usage of the Myhill-Nerode relation were also found to be challenging.

Chapter 4

Concept and Didactical Decisions

In the previous chapters, the motivation for this work was presented, and the research questions were derived. Afterwards, cognitive theories on multimedia learning and a theory of learning styles were analyzed to get design recommendations for the Learning Units. Additionally, existing approaches combining e-learning and theoretical computer science and other articles on related e-learning usage were analyzed to extract further design recommendations. Studies on the learning difficulties of students in courses on theoretical computer science were considered, to gain further insights into the concerned areas. In this chapter, the intended learning outcomes and the concept will be described. First, the competencies the Learning Units aim to aid in conveying will be presented, followed by a description of the content of the Learning Units. Then, the concept of the Learning Units will be described, followed by an overview of the respective didactical decisions. It is shown how the design recommendations were implemented, and finally insights into the realization are given for all Learning Units.

As already mentioned in Section 1.1, the Learning Units cover only a small part of theoretical computer science and are used as a supplement. The courses themselves are held without alterations.

4.1 Competencies and Content

This section will start with a definition of the term competency, followed by a discussion of the competencies and content for the Learning Units. The Learning Units are created as a supplement for two university courses. The competencies and content for each course will be discussed separately, for an improved distinguishment.

In the last decades, the importance of teaching in an outcome-oriented way has risen more and more. These outcomes are most often stated as so-called competencies the student is meant to acquire in a given course. However, defining and measuring such competencies is a complex task. In [ZSK15], Zlatkin-Troitschanskaia, Shavelson and Kuhn discuss successes and problems concerning research on the measurement of competencies in higher education in recent years. They discuss several specific as well as generic research approaches where competencies have been measured in different disciplines. However, they also discuss the complexity of measuring and especially comparing competencies in-between different countries and degree programs. In [Wei01], Weinert discusses several complications in precisely defining what competencies are. A rather practical definition for the term competency is given by Klieme and Leutner [KL06], defining competencies as context-specific cognitive dispositions, acquired by learning and necessary to successfully cope with certain situations or tasks in specific domains. Brinda and Kramer [BK19] state that a competency is not measurable in a direct fashion but can, for example, be measured by the ability to fulfill a certain task or solve a certain exercise. So-called competency models are commonly used for a certain area (or course) to distinguish different competencies on different levels of difficulty that might be acquired. In [BK19], Brinda and Kramer give a brief overview of current developments considering competency models in the area of computing education.

For theoretical computer science, there is so far no validated, researched way of measuring competencies. For example, Schlüter and Brinda state in [SB08b] that for their concerned area of theoretical computer science in secondary schools, competencies have been formulated, but without a communicated way how to measure them. Frede and Knobelsdorf state on FLAT topics that "well established instruments to precisely measure domain-specific competences in this field are missing"[FK18]. In [SB08a][SB08b], Schlüter and Brinda discuss the possibility to create a competency model for theoretical computer science in secondary school education derived from exercises, but there seem to be no published final results of this process. The German Informatics Society published a competency model for the area of formal languages and automata theory in [Ges16], but also without further instruction on how to measure these competencies. For the Learning Units, exercises were created with regard to typical exam or homework exercises and the aim to create exercises as useful as possible in acquiring the respective competencies.

As already mentioned briefly in the overview in Section 1.1, the content for the Learning Units originates from two courses at Technische Universität Berlin. The first course is called *Formale Sprachen und Automaten* (which translates to formal languages and automata). From this point onward, this course will be abbreviated as FLAT. The second course is called *Reaktive Systeme* (ReSyst) (which translates to reactive systems). Both courses cover different topics, and for each course, two Learning Units were created based on the concept presented in this chapter.

4.1.1 Competencies and Content for FLAT

The FLAT course was chosen as it is a common course for computer science students at different universities and even in different countries, covering important basics of theoretical computer science. The competencies that should be acquired in the two Learning Units concerning the FLAT course are:

1. Using fundamental tools of computer science.
2. Applying algorithms and proof methods.
3. Using formal languages and automata confidently.
4. Understanding properties of formal languages and automata.

This list of competencies is based on the description of the intended outcomes of the FLAT courses at Technische Universität Berlin [Teca], Universität Duisburg-Essen [Unic] and Universität Potsdam [Unie] and the recommendations for bachelor and master computer science programs by the German Informatics Society [Ges16].

The first Learning Unit covers deterministic finite automata and non-deterministic finite automata and how these automata accept regular languages. The powerset construction is used to show how a non-deterministic finite automaton can be transformed to a deterministic one. This construction is important for proving that both accept the same languages. Additionally, the pumping lemma is covered to prove that a given language is not regular. The second Learning Unit covers the minimization of automata using the table-filling algorithm and the Myhill-Nerode relation. The latter can be used to show whether 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 alongside the languages they accept for the deterministic and non-deterministic case.

This content relates to the competencies stated above in a straightforward fashion, especially the competencies 3 and 4. As building a model (e.g. an automaton) that is related to certain properties (e.g. accepting words of a formal language) and proving properties concerning this model all can be seen as fundamental tools of computer science, the content also relates directly to competency 1. Automata accepting languages, the powerset construction, the pumping lemma, the minimization of automata – all these are applications of algorithms and proof methods and therefore relate to competency 2.

These topics were chosen as they are a mixture of topics that often lead to problems in homework and exams (e.g. the pumping lemma, the usage of the Myhill-Nerode relation and the construction of pushdown automata). Furthermore, content was used that is fundamental for these problematic parts (e.g. the usage of DFAs and NFAs). This content relates directly to the recommendations presented in Section 3.4. The recommendations on content in this area covered in general a need for abstraction, conceptualizing proofs, mathematical notation and formal proving. In particular, the pumping lemma, the conversion of non-deterministic to deterministic finite automata, the construction of pushdown automata and usage of the Myhill-Nerode relation were listed as content areas with large learning difficulties.

Both Learning Units are estimated to have an overall similar level of complexity for the students as both contain rather algorithmic tasks (e.g. automata transformation / the table-filling algorithm), as well as more complex tasks, students typically have problems with (e.g. the pumping lemma / using the Myhill-Nerode relation).

4.1.2 Competencies and Content for ReSyst

The ReSyst course was chosen as it is more advanced compared to the FLAT course, with a different target group that has further progressed in their course of study. The idea was to show the applicability of the concept of the Learning Units for a different target group and a different content area of theoretical computer science. The competencies that should be acquired in the two Learning Units concerning the ReSyst course are:

1. Understanding the theoretical foundations of concurrent systems.
2. Modeling and comparison of concurrent systems.
3. Understanding the semantic concepts.
4. Applying theoretical concepts to solve formal tasks.

This list of competencies is based on the description of the intended outcomes of the corresponding courses at Technische Universität Berlin [Tecb], RWTH Aachen University [RWTb], Universität des Saarlandes [Unia] and Universität Duisburg-Essen [Unid].

The first Learning Unit covers trace equivalence and strong bisimulation to compare processes. Proofs are covered to show that one component in a labeled transition system (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. To prove weak bisimulation, proofs similar to those for strong bisimulation are presented.

The second Learning Unit 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.

Again, the relation between the competencies stated above and the content can be seen rather directly. The competencies 1 and 2 can especially be related to the comparison of concurrent systems from different points of view, in this case, trace equivalence and strong and weak bisimulation. Competency 3 directly to concepts like bisimulation, but also to fixed point theory, which is a strong focus of the second Learning Unit. Competency 4 relates to the computation of bisimulation relations on the one hand and the computation of fixed points on the other.

Again, these topics were chosen as they regularly lead to problems and confusion in homework or exams (e.g. distinguishing processes by strong and weak bisimulation and applying fixed point theory to compute the largest bisimulation).

Furthermore, fundamental parts for the corresponding course (e.g. comparing processes with bisimulation and proving or disproving their relation and the fundamental notions of the fixed point theory in question) were chosen. This content relates to the more abstract areas proposed by the study results in Section 3.4, like abstraction, conceptualizing proofs, using mathematical notation and formal proving in general.

Both Learning Units are estimated to have an overall similar level of complexity for the students, even though they emphasize different aspects.

The first Learning Unit emphasizes different notions of comparing processes. This content often confuses students considering the implications of the differing viewpoints and the involved systematic proofs.

The second Learning Unit involves a rather complex theoretical aspect (why under certain circumstances fixed points exist and why they can even be computed) and a rather algorithmic straightforward way to apply this theoretical aspect (or its consequences) to compute the largest bisimulation in a given setting.

4.2 Concept

This section will present the general concept of the Learning Units. For the remainder of the dissertation, used images in German language are generally not translated. The reason for this is that the relevant aspects illustrated by the images are independent of the actual text.

As the Learning Units are all of the same structure, the concept is the same for each of the four Learning Units. In the subsequent remainder of the chapter, the decisions leading to this concept and its correspondence to the design recommendations will be discussed. This will be followed by insight into the actual implementation of those units.

Figure 4.1: One of several blocks for content in one of the Learning Units.

Each Learning Unit is implemented as one Moodle course. The Units are separated into blocks on their different content parts. One such block can be seen in Figure 4.1. The headline and the short introductory text explain what the content of this block is. One block contains one or two links to lessons (with the three linked blue boxes). These lessons contain the actual content explanations, arranged on different learning paths. On these paths, questions are posed to deepen the understanding of this content as well.

Furthermore, each block contains a link opening a quiz with further complex questions on the content (with a red checkmark) for the learners to further test their knowledge and deepen their understanding. Below this, there is the link to the bonus page (still greyed out). It contains 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 4.3.

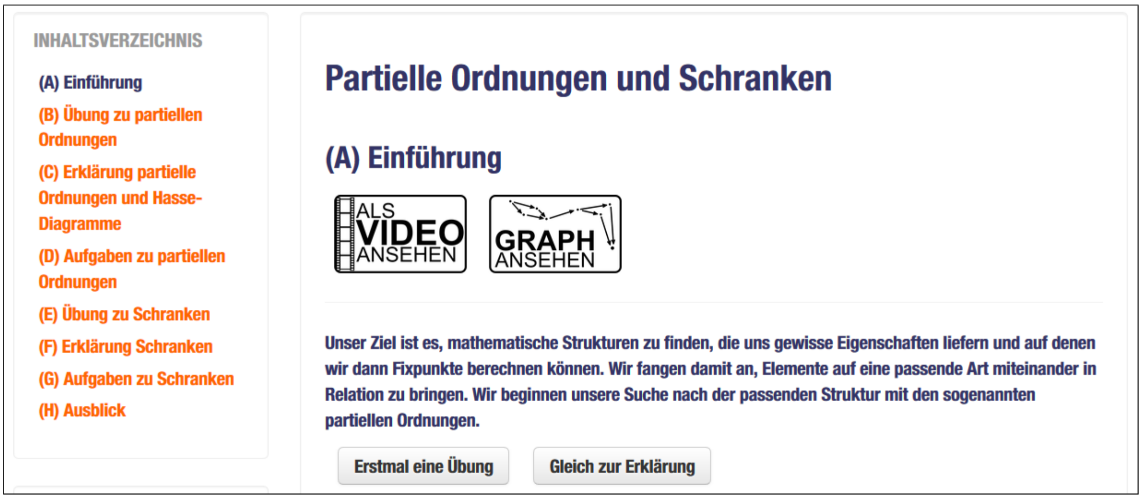


Figure 4.2: Cutout of the first page of a lesson on partially ordered sets and upper and lower bounds.

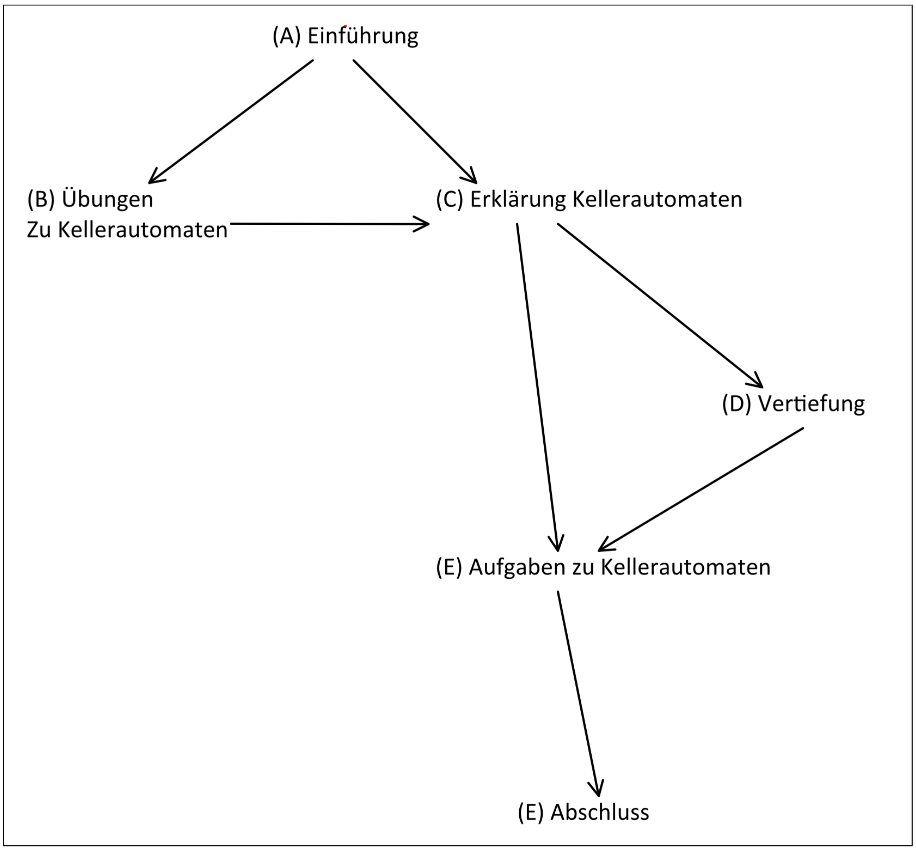
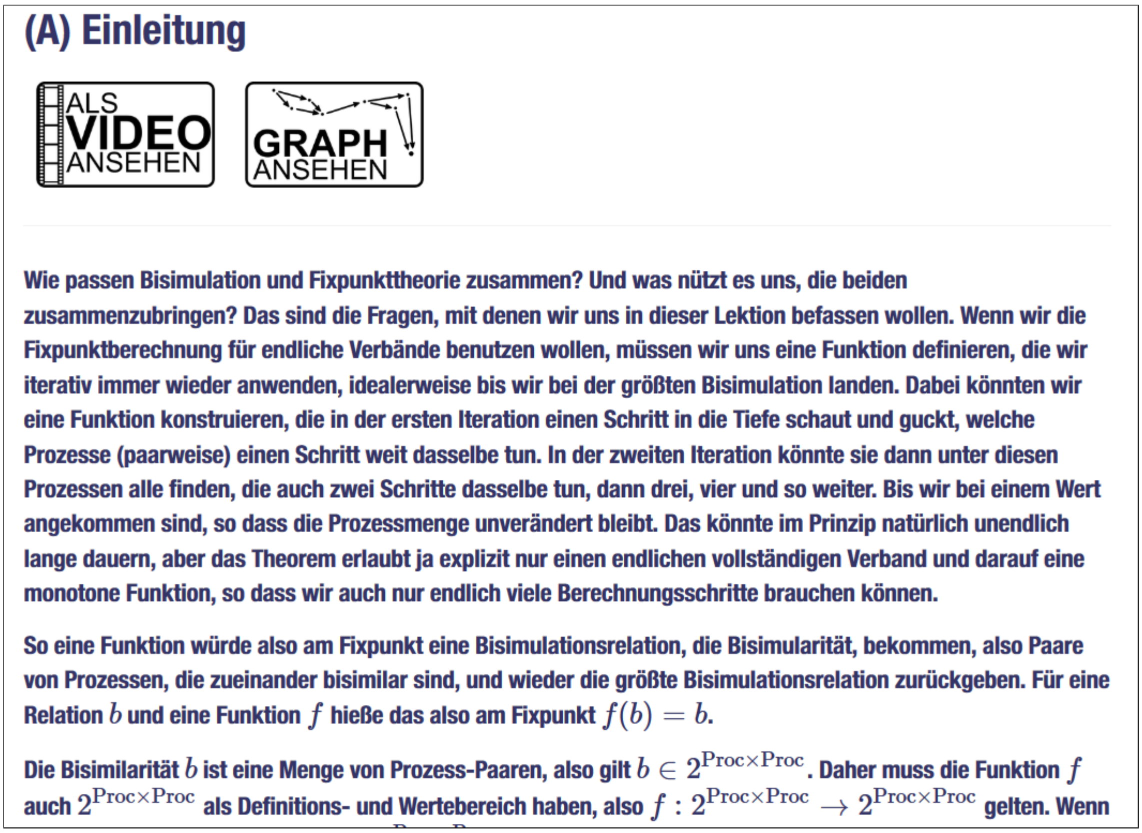


Figure 4.3: Lesson graph indicating the different learning paths for one lesson.

Figure 4.2 shows part of the characteristical first page of a lesson (after one has clicked on a link with the three linked blue boxes). On the left side, there is the navigation bar to allow students to navigate to lesson parts without necessary following the intended order. Below the headline, two large buttons are visible. The left one leads to the same content as shown on the page, but presented as a video.

The textual presentation is always shown first. The content of the video is identical to the textual form, with the text being read in its entirety as audio track, and visualizations of formulas and connections (often more graphical than in the pure textual form) are shown in the video. The right button opens the graph of this lesson, showing the different possible learning paths. An example of such a graph can be seen in Figure 4.3. The following text on the page gives a short overview of the lesson.



(A) Einleitung

ALS VIDEO ANSEHEN

GRAPH ANSEHEN

Wie passen Bisimulation und Fixpunkttheorie zusammen? Und was nützt es uns, die beiden zusammenzubringen? Das sind die Fragen, mit denen wir uns in dieser Lektion befassen wollen. Wenn wir die Fixpunktberechnung für endliche Verbände benutzen wollen, müssen wir uns eine Funktion definieren, die wir iterativ immer wieder anwenden, idealerweise bis wir bei der größten Bisimulation landen. Dabei könnten wir eine Funktion konstruieren, die in der ersten Iteration einen Schritt in die Tiefe schaut und guckt, welche Prozesse (paarweise) einen Schritt weit dasselbe tun. In der zweiten Iteration könnte sie dann unter diesen Prozessen alle finden, die auch zwei Schritte dasselbe tun, dann drei, vier und so weiter. Bis wir bei einem Wert angekommen sind, so dass die Prozessmenge unverändert bleibt. Das könnte im Prinzip natürlich unendlich lange dauern, aber das Theorem erlaubt ja explizit nur einen endlichen vollständigen Verband und darauf eine monotone Funktion, so dass wir auch nur endlich viele Berechnungsschritte brauchen können.

So eine Funktion würde also am Fixpunkt eine Bisimulationsrelation, die Bisimularität, bekommen, also Paare von Prozessen, die zueinander bisimilar sind, und wieder die größte Bisimulationsrelation zurückgeben. Für eine Relation b und eine Funktion f hieße das also am Fixpunkt $f(b) = b$.

Die Bisimilarität b ist eine Menge von Prozess-Paaren, also gilt $b \in 2^{\text{Proc}\times\text{Proc}}$. Daher muss die Funktion f auch $2^{\text{Proc}\times\text{Proc}}$ als Definitions- und Wertebereich haben, also $f : 2^{\text{Proc}\times\text{Proc}} \to 2^{\text{Proc}\times\text{Proc}}$ gelten. Wenn

Figure 4.4: Cutout of the first page of a lesson on the relation of bisimulation and fixed points.

Figure 4.4 shows a different first lesson page, already containing first explanations on the topic. Below each page, the learner can choose where to go next on the learning path using buttons. More explanations on the learning paths can be found in Section 4.3. For example, the left button in Figure 4.2 leads to introductory exercises for the following topic, the right one to the explanation for the next piece of content.

All further lesson pages on content are basically constructed in the same way, apart from the button to show the lesson graph. This button is only shown on each respective first page.

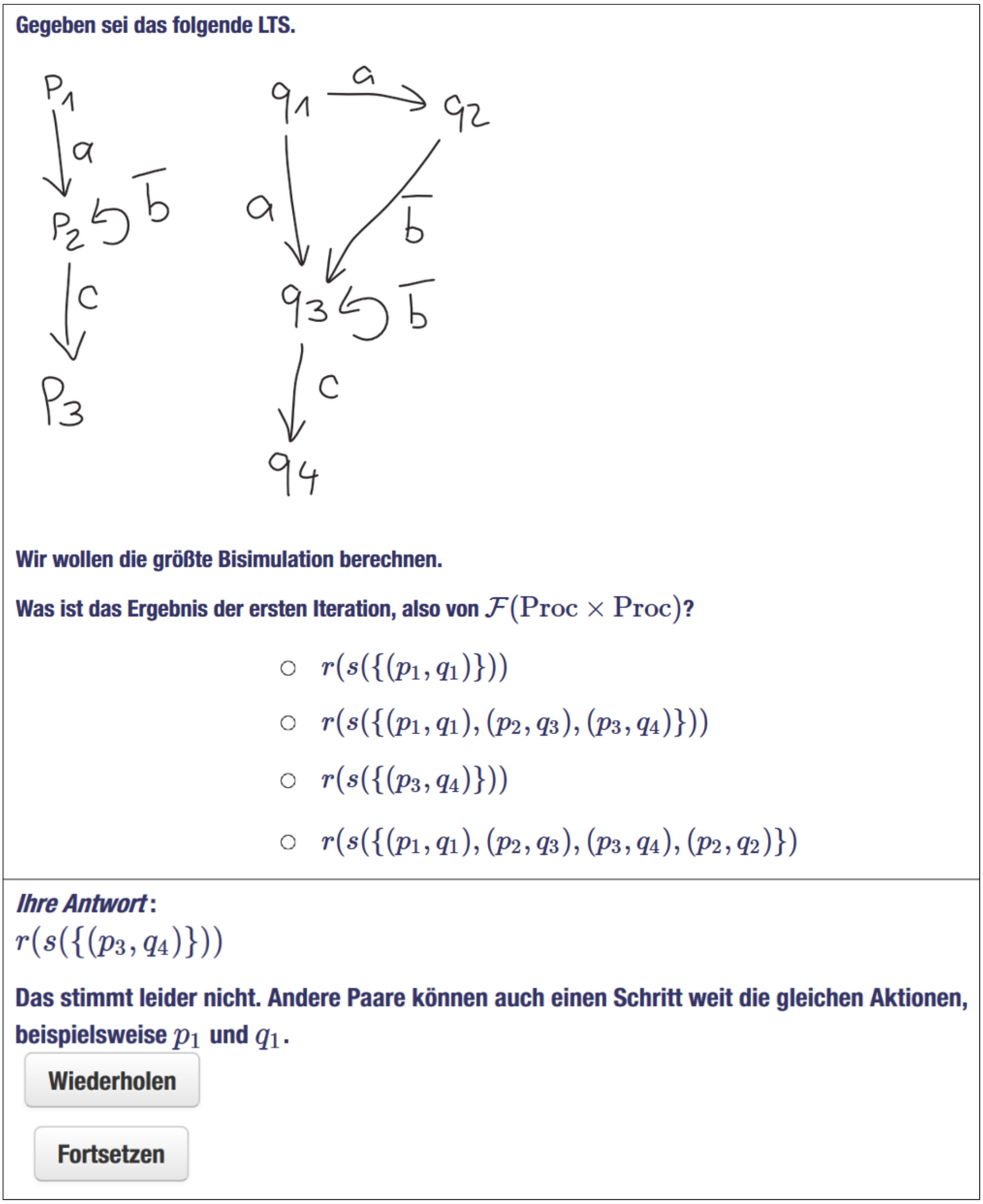


Figure 4.5: Multiple-choice exercise and feedback shown after answering.

In Figure 4.5, a typical single-choice question can be seen, where the learners can choose their 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 give learners two choices: the learners can repeat the question or continue with the next question.

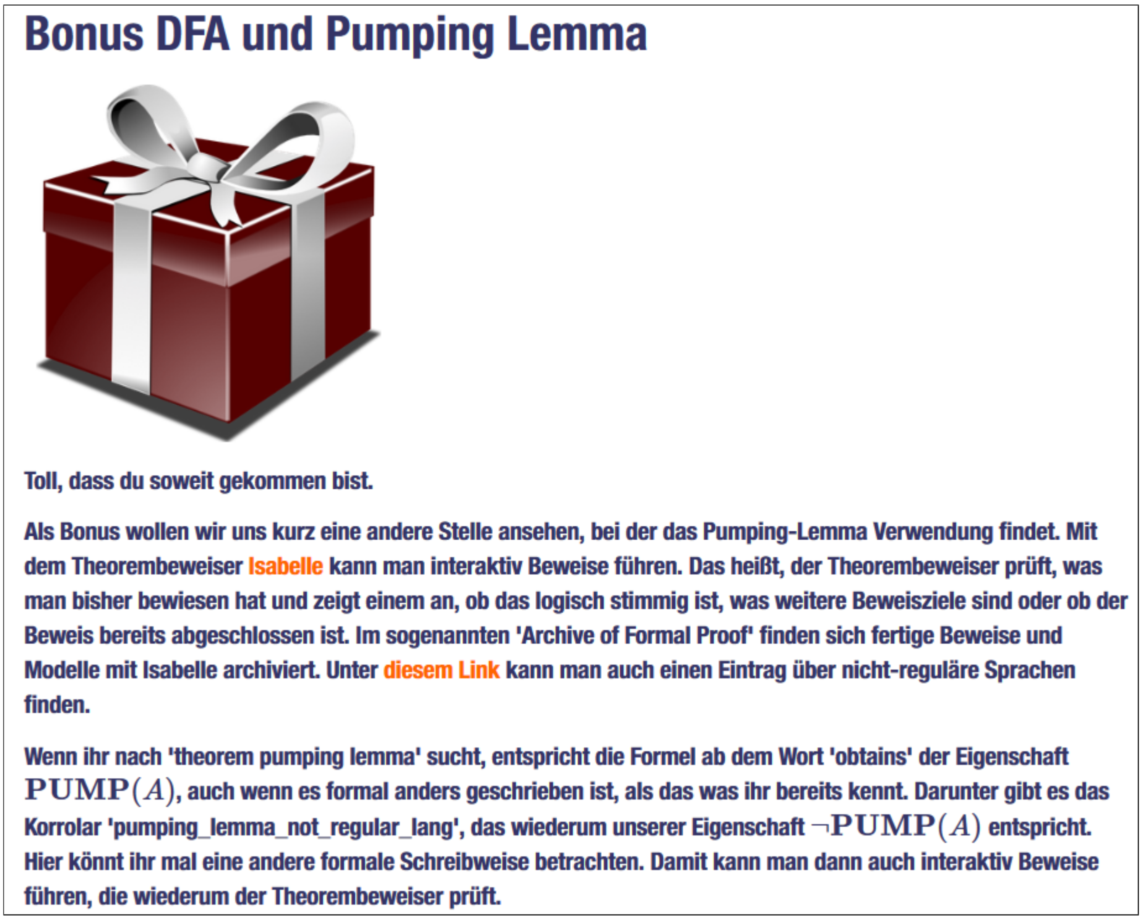


Figure 4.6: Bonus page that can be unlocked after enough questions were answered correctly.

Questions may be repeated, for example, to improve the score to unlock the bonus page of this block. Continuing with the next question is always possible, regardless of the fact whether the answer was correct or incorrect. Repeating questions at a later point in time is also possible.

If the student reaches the hurdle and therefore has answered enough questions correctly, a bonus page like the one in Figure 4.6 can be permanently unlocked and accessed. These bonus pages contain open questions on the content of the Learning Unit, further information or even unusual exercises or different approaches on the content, like a proof in the interactive theorem prover Isabelle/HOL[1]. In the following, the term open questions always refers to questions with the aim to get students to reflect about the content. For such questions, no answers or feedback are given.

In using the Learning Units, students either get introduced to new content, or use them for repetition. Depending on their knowledge level and interest, they can choose to follow the learning path they prefer, where they are presented with content and questions on this

[1] `https://isabelle.in.tum.de/`

content. Typically, the pool of further questions on the content (with the red checkmark as its sign) is used for repetition or to test the students' understanding. If the students prefer it, they can also start with these harder questions or answer them whenever it fits best in their learning process. If they perform well enough, the bonus page is unlocked permanently for this user to be displayed.

A possible disadvantage is that students might not notice the supplementary character of the approach and use solely the Learning Units for their preparation 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 or homework. 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 be uploaded and corrected manually, for example. In [Her13], Herding analyzes such possibilities extensively in the so-called "tutor in the loop model".

4.2.1 Using the Categories

This section will present a step-wise analysis of the concept and its origins, based on the categories presented in Section 3.3.

Firstly, the questions on appropriateness of the setting will be answered.

What is the target group?

The target group of the Learning Units is mainly considered to be computer science students at bachelor level. Students of a few other study programs, most of them with a technical or mathematical main focus, are also participating in these courses. A small preliminary study was done with students that had already heard the courses. These students were invited to test the questionnaires as well as the state of the Learning Units at the time. This testing was done in the presence of the author. The preliminary study will be discussed further in Section 5.2. Testing the Learning Units was especially useful to find out whether members of the aforementioned target group are spontaneously able to use the Learning Units, where they see hindrances in their usage, and what their first impression is. Apart from the need for a better overview concerning the lesson paths, the first impression of the students was highly positive. The overview was improved by the addition of the lesson graphs. Such a graph is presented in Figure 4.3. The results of this preliminary study lead to the basic assumption that the Learning Units seemed to be appropriate for the target group.

How much effort is intended?

To decide upon this matter, several aspects had to be considered. The existing main idea was to create an approach to help students in learning content on theoretical computer science. As videos are a useful way to explain complex content (e.g. proofs) vividly, the integration of videos had also been planned in an early stage. As creating videos already creates a vast effort (as, e.g., discussed by Nestmann and Wilhelm in [NW14]) and to prevent overloading or blurring the approach, the complexity in creating further elements beyond the necessary (i.e. content explanations and questions) was kept as easy as possible. The development of serious games (like, e.g., the one discussed by Schäfer et al. in [SHL+13]) or interactivity in videos were discarded as options. The only other element which took huge effort to create, were the questions. The creation of multiple-choice or single-choice questions on this content was a complex issue. The effort for maintaining the approach was intended to be rather low, which was achieved. Based on the idea not to further increase the effort, hands-on exercises like the tool-based ones discussed in Section 2.1.2 were not integrated in the approach. As the Learning Units are to be used as a supplement, using them can easily be combined with tool-based approaches in one course.

Which type of multimedia-based learning will be used?

As the intention of this work was to facilitate learning in courses on theoretical computer science without the necessity of instructors changing their courses, and therefore creating an easily applicable approach, the choice for the supplementary use discussed in this dissertation was straightforward. MOOCs or other possibilities were not used, as it was deemed to be useful to concentrate on those parts that can be implemented beneficially in e-learning without removing the pencil-and-paper work done in most courses.

How much variation will be integrated?

Based on the basic assumption of different personal preferences of learners, the idea to integrate variation, which is e.g. discussed as an important attribute by Cogliati et al. in [CGG+05], existed. The choice for the Learning Units was not to integrate variation in the way Cogliati et al. propose, with a variety of general elements to be used. Instead this was integrated by a choice between forms of presentation of exactly the same content as text or video. To the best of the author's knowledge, this was not integrated similarly in such an approach before.

What elements will be used?

The chosen basic elements were text, videos and questions. For questions, it was decided not to use a large variety of question types. In the beginning, it was planned to use a variety of question types for the lessons. However, over the course of the development, the question types were reduced to single-choice and multiple-choice questions to concentrate more on the quality of these question types. The creation of the questions will further be discussed in Section 4.5.

What further technical aspects should be integrated?

The only further technical aspect that was considered was adaptivity, where the platform and the possible options change depending on the learners' progress or learning style. Prototypical implementations for the latter were, e.g., presented by Graf and Kinshuk in [GK08] or by Liyanage, Gunawardena and Hirakawa in [LGH14]. Such an approach was discarded to give students full control over the learning process. In [Tsc04], Tscherter even states that adaptive and therefore changing behavior might lead to confusion for the learners.

Which platforms are appropriate?

Moodle as a platform met all criteria above and was familiar to the author as well as to students at Technische Universität Berlin and several other universities, which was assumed to be a useful advantage. The platform is open source, which is useful, as there are no further costs to the approach beyond maintaining a server, which could fortunately be done at Technische Universität Berlin. Moodle is also developed towards better accessibility, considering international standards, as the developers state in [Mooa]. Furthermore, in the comparison of learning management systems by Graf and List [GL05], Moodle outperforms all other platforms, for example on usability and concerning learning objects. The lesson module, in this approach used for the content presentation, is especially mentioned positively. An alternative would have been the ILIAS[2] learning management system. Moodle was chosen over ILIAS based on the experience of the author working with Moodle. Blackboard[3], another successful learning management system, was discarded as it is not available open source.

Secondly, questions regarding content will be answered.

Are online elements to be aligned with offline elements?

As the general idea of the approach was to facilitate learning for students in actual courses, the Learning Units were aligned to such courses. Here, four weeks of each of the two courses in Berlin were used exemplary after initial investigations that similar course structures exist at other universities.

[2] `https://www.ilias.de/`
[3] `https://de.blackboard.com/`

Are choices and intended learning outcomes aligned?

As the intended learning outcomes were synthesized from the intended learning outcomes of such courses, as described in Section 4.1, this alignment was a strong focus of the creation of the Learning Units.

What is necessary for this content area?

As discussed both in Section 2.1 and Section 3.3, the most important elements to be used regularly are formulas and proofs. These elements had to be implemented in a way enabling the editing of parts without too much effort. This could be achieved by using a plugin that is able to automatically render a huge amount of formulas in the markup language LaTeX[4], which is inter alia regularly used for the typesetting of documents containing formulas. In this way, a formula like $\forall x \in A.P(x)$ could be written as

```
$$\forall x \in A. P(x)$$
```

which is the normal syntax for LaTeX and easily to be edited with a reasonable amount of experience. In the case of the Learning Units, displaying graphical representations of automata was also necessary. This was not achieved directly in Moodle. Instead, these were created with a vector graphics editor and then uploaded to Moodle. This allowed for simple changes still being possible in a reasonable amount of time.

The third question to be answered is:

Is there attention to cognitive ergonomics?

Attention to cognitive ergonomics was achieved, on the one hand, by following the recommendations of the cognitive theories discussed in Section 3.1. How these recommendations were implemented will be discussed in Section 4.4. On the other hand, attention to cognitive ergonomics was achieved by taking the user experience (UX) of Moodle into consideration[5]. UX is described by Laugwitz, Schrepp and Held in [LSH06] as the way a product is experienced by a user, considering inter alia how predictable, efficient or stimulating it is. The international standard ISO 9241-210 defines UX as "user's perceptions and responses that result from the use and/or anticipated use of a system, product or service". The developers of Moodle themselves discuss how important usability as part of the UX is in their work on their homepage [Moob]. In [MT07], Machado and Tao compare the UX of Moodle and the well-known learning management system Blackboard. Their results suggest that Moodle has the better UX for the user. As already mentioned, in [GL05], Graf and List examined several platforms and found that Moodle outperforms the other

[4] `https://www.latex-project.org/`
[5] This was discussed extensively in [WN18]

platforms concerning adaptivity and usability. In contrast, Kirner, Custódio and Kirner [KCK08] conducted a study with usability experts. The findings showed that all other platforms used in this study outperformed Moodle concerning usability. The usability and the whole UX of a platform with such a huge range of possible uses is hard to grasp in its entirety. Therefore the UX for the approach in this dissertation was analyzed as part of the studies as a possible problem source or influence on the usage of the Learning Units.

Fourthly, questions on interaction will be answered.

What interaction with people is possible?

The students had the possibility to use a discussion board for exchange with the author and fellow students and the possibility to send private messages. The idea here was to reduce the number of interactions, for students to be independent of each other. Participation in the studies was rather low, as will be discussed inter alia in Section 5.6. Possibly, this design decision to reduce interactions was not ideal from this point of view, as personal interactions might have further motivated students to use the Learning Units. In [NPB18], Nortvig, Petersen and Balle discuss the importance of social interactions for successful e-learning extensively.

What interaction with the platform is possible?

In general, the students had the possibility to interact with the lessons and quizzes in the form of single-choice and multiple-choice, in choosing the way the content was presented to them, and in their navigation along the Learning Units. Apart from the bonus pages, every part was accessible all the time. Additionally, the students could follow different learning paths inside the lessons, where they could always decide whether they wanted to be introduced to new content by the so-called preliminary exercises leading up to the content or view the explanations directly. In several cases after content pages, students could decide to go straight to the exercises on the content or first proceed to an extension on the content. Such extensions usually explain content for more in-depth understanding of the topic. For each answered question, the students received feedback on their solution.

The fith and sixth question open up different perspectives on assessment – assessing the students in the course and evaluating the platform itself:

How are students assessed?

In the courses the studies are conducted in, student assessment mostly comprises homework and either a written or an oral exam. The Learning Units are not tailored to be combined with one or another particular type of assessment in the course.

How is the platform evaluated?

The Learning Units were evaluated formatively in the process of development. Talks were given at different stages, presenting the current state of the Learning Units, e.g. at Technische Universität Berlin at several occasions, and once at Universität Hamburg in a research group on the didactics of computer science. Furthermore, the Learning Units were discussed at a conference in Marburg and in many conversations with researchers (and course instructors) and assistants in the fields of theoretical computer science – several times in the process of planning the different studies – as well as in the field of didactics of computer science. As part of the summative evaluation, the final concept (sometimes in combination with first results) was presented and discussed in a doctoral colloquium for PhD students in the field of didactics of computer science held in Berlin at the time, at conferences in Copenhagen in Denmark, Koli in Finland, Tampa in the USA and in a research group on didactics of computer science at Humboldt-Universität Berlin. All presentations were given by the author except for the one in Finland. This talk was given by Nadine Bergner. The main part of the summative evaluation are the six studies in five locations. The study structure and surveys will be presented in Chapter 5, the results will be presented in Chapter 6.

4.3 Didactical Decisions

In this section, the main decisions in creating the Learning Units from a didactical perspective will be discussed, along with the reasons for these decisions.

Learner-orientation: In [BD03], Blass and Davis discuss the fundamental changes in past and present towards a learner-oriented learning experience and how these are in line with basic principles of e-learning. Learning with e-learning material is independent of a certain place (like a lecture room or classroom), of the time of day or the pace of the learner. If learners using the Learning Unit want to pause at any time, skip parts of the content or hear/read an explanation again, they can choose this themselves, independent of other learners. Students who can not follow at the pace of a lecture in class can easily deepen their understanding at home later, using the Learning Units. They can also use the Learning Units before the lecture or tutorials for preparation to improve their understanding in the attendance phases. All these factors create an **individual** learning experience.

Users are able to learn in a **self-regulated** fashion. In [Zim02], Zimmermann discusses the importance of self-regulated learning, learning that is done in a proactive way, based on the students' initiative. Usually, this involves them to monitor and reflect their own learning process closely. According to Zimmermann, self-regulated learning improves effectiveness and motivation as well as self-satisfaction of students. Otto, Perels and Schmitz [OPS11] also discuss the importance of self-regulated learning from a constructivist point of view. They see it as an important part of modern learning and summarize a study where self-regulated learning abilities were a significant predictor for success in a test.

The Learning Units give students by design the opportunity for such learner-oriented, individual learning experiences and self-regulated learning.

Personalized language: In [NHHM$^+$13], Niegemann et al. discuss the usefulness of a personalized, conversational language for e-learning to create a social interaction with the learner. Especially the explanations in the lessons are formulated in a personalized, conversational language.

Learning paths: In [Bla07], Blankenagel discusses advantages and disadvantages of different possibilities considering learning paths in e-learning systems, where students can follow a number of paths between objects. A huge number of different possibilities gives learners more individuality. A lower number leads to simpler orientation. Inside each lesson in the Learning Units, the learning paths always branch when there is new content. Either the student can first approach the new content based on selected exercises, or go directly to the content explanations. Additionally, at several points, students can proceed to a content extension after a content page to deepen their knowledge. These decisions on learning paths were based on balancing the possibility for students to take decisions on their paths through the lesson, but at the same time avoiding confusion.

Direct feedback: In [GG11b], Gräsel and Göbel discuss the importance of feedback for learners when working on an exercise. Nortvig, Petersen and Balle [NPB18] also discuss the importance of feedback, in this case, especially for e-learning approaches. Niegemann et al. [NHHM$^+$13] stress the importance of feedback in e-learning to enable learning processes. As was already discussed in Chapter 1, typical exercises in theoretical computer science (those without using hands-on tools) are done with paper and pencil, and so are also most homework exercises. Therefore, waiting for the graded version takes much time. For the students, this usage of paper and pencil is an important part, as students should be able to derive their own solutions and proofs manually. However, using the Learning Units beforehand enables the students to get direct feedback and can possibly reveal misconceptions or problems at an early stage. An additional part of general feedback is that Moodle shows the students their progress in the lesson as a percentage displayed in a progress bar. Therefore they are able to estimate better how much they already worked on a topic.

Variability: The Learning Units offer learners the possibility to choose between a presentation of the content as text or video. The aspect of differences in learners' preferences has already been discussed for this design decision. In [NDH+08], Niegemann et al. emphasize the usefulness of variability to maintain the interest of the students. This holds as long as the variability is predictable for the learner.

Interactivity: Interactivity is integrated in the Learning Units on navigation, answering the questions and the choice of content presentation. Schubert and Schwill [SS11] call interactivity one of the characteristic properties of computing systems. Niegemann et al. [NHHM+13] discuss the widespread use and usefulness of interactivity. Schulmeister [Sch02] presents a taxonomy of interactivity, with five stages: (1) observing objects, (2) choosing in-between multiple forms of presentation, (3) varying the form of representation, (4) modifying content and (5) constructing content. The Learning Units doubtless integrate stages (1) and (2) of this taxonomy by their content and the choice of presentation forms. The single-choice and multiple-choice questions with feedback allow for more interactivity, which is not perfectly met by the model but can be seen as part of stage (3). The main practical reason for not integrating more advanced possibilities for interactivity were to reduce the effort for instructors when implementing the approach. It is important to note here that Schulmeister distinguishes between interactivity and navigation. Therefore the latter was not considered in this classification, even though the learning paths can be seen as interaction beyond pure navigation.

Mastery learning: In [Blo68], Bloom introduced the idea of mastery learning. The aim was to get students to work on content in the pace useful to them until they had proven their mastery in it. He also stated that students should feel rewarded for reaching a level of mastery. Therefore, bonus pages were introduced for each block in the Learning Units. Students can attempt solving exercises in each block as often as they want and therefore learn in their individual pace. When they have solved at least 75 percent of the exercises in one block (lessons and the additional quiz) correctly, the bonus page is unlocked as a reward, displaying additional information or exercises. Reaching this hurdle by guessing is theoretically possible for students. However, it seems unlikely based on the number of questions per block in the lesson or lessons and the pool of further questions.

4.4 Recommendations of Cognitive Theories and Learning Styles

This section will summarize step by step how the design recommendations based on cognitive theories and learning styles worked out in Chapter 3 were implemented in the Learning Units. A short overview of the recommendations can be found in Section 3.5.

Considering the CLT, the design recommendations could be implemented very directly. Worked examples were integrated into the content explanations wherever possible. This is especially necessary in more complex tasks like the proofs of the pumping lemma or corresponding to computing the largest bisimulation based on fixed point theory. Images had to be especially integrated with corresponding text only few times, as for most images used in the Learning Units (mostly graphical depictions of automata), it is already common to put text into the images. Redundant text and explanations were avoided as far as possible. Partially completed problems could be integrated into the single-choice and multiple-choice questions. Presenting part of a proof or exercise and asking for the next step has proven to be a useful type of exercise. Voice and images were used in combination in the videos. Explanations were generally aimed at transporting clear guidance on problem-solving, in addition to the worked examples. To avoid increasing cognitive load, a clear structure was used, only presenting a very small number of elements at a time, e.g. the number of elements in each block or the number of possible decisions on each lesson page. The introductory text for each block and at the beginning of each lesson were created to facilitate schema acquisition.

Based on the CTML, active processing was supported implicitly by asking the students to take their own paths through the Learning Units and by integrating the other aspects recommended by the CTML to facilitate the learning process. Words and pictures were combined wherever possible in the content presentations as text as well as video. Irrelevant material was excluded apart from the bonus pages, where sometimes the facts presented are related to the content but irrelevant for the actual content of the Learning Unit. A conversational style was used throughout the Learning Units. Combined animation and on-screen text were avoided as often as possible, as was the combination of these two elements with additional narration.

The recommendations of the CATLM included the use of explanatory feedback, which was given after each answered question. Students were given control of the learning pace. The preliminary examples before each content explanation that could be chosen along the learning paths allowed the introduction of pretraining to activate the learners' prior knowledge or prepare them for the upcoming content. Individual differences of students were considered in a way that they could choose between presentation as text and video, choose their own speed and order of learning and use the learning paths. Interactivity was integrated by the same possibilities as these individual differences, combined with the possibility to answer questions on different difficulty levels in the lesson and as part of the additional quizzes.

The recommendations based on the Felder-Silverman learning style model led to the motivation of content at the beginning of each block as well as each first lesson page. As the concerned area of theoretical computer science heavily uses theoretical explanations, integrating both theories and facts was not successful as a whole. Understanding and exercises were balanced by alternating exercises and content explanations. Illustrations were provided wherever possible. Opportunities for activity were integrated mainly in the form of the single-choice and multiple-choice questions.

Overall, integrating the design recommendations based on CLT, CTML, CATLM and the Felder-Silverman learning style model was possible in the development of the Learning Units and matched well with the didactical decisions.

4.5 Realization

In this section, an overview of each of the four Learning Units[6] that were created by the author for this dissertation is given. Additionally, insight into the creation process will be given, where it is insightful. The section will especially focus on the peculiarities of these Learning Units. All Learning Units are constructed similarly and have the same degree of interactivity.

The Learning Units were created using a Moodle installation on a server located at Technische Universität Berlin. For the creation of images in the Learning Units, the programs Affinity Photo[7] and Affinity Designer[8] were used. The voice for the videos was

[6] Accessible at: `http://typo.service.tu-berlin.de/course/view.php?id=21`
[7] `https://affinity.serif.com/de/photo/`
[8] `https://affinity.serif.com/de/designer/`

recorded using the free program Audacity[9]. Screen capturing and the video editing were done using Camtasia[10] by Techsmith.

For transferability of the general approach, only two minor alterations were included in Moodle: (1) One button was added to each content page of a lesson, linking back and forth between the text and video presentations. (2) On the first page of each lesson, another button for the graphs considering the learning paths was added.

Many modules of Moodle were not used in the approach, to avert overloading the general approach on the one hand and to prevent overstraining the learner by a multitude of possibilities. The need for a reduced number of elements was, e.g., emphasized by Blass and Davis, who stress the importance of a clear structure in their overview of criteria for e-learning in [BD03].

In [BEF+56], Bloom et al. presented a taxonomy of educational objectives to classify and compare cognitive goals of teaching. The stages of this taxonomy, ordered by increasing complexity, are:

- Knowledge
- Comprehension
- Application
- Analysis
- Synthesis
- Evaluation

The single-choice and multiple-choice questions will concentrate mainly on the levels of comprehension, application and analysis. The analysis of the relationships between objects and their communication in particular forms important parts. Additionally, the questions follow the multiple-choice item-writing guidelines synthesized by Haladyna, Downing and Rodriguez [HDR02]. Examples for these resulting guidelines are, e.g. to avoid trivial or trick items and to keep items independent. The guidelines also contain content-independent guidelines, e.g., to format items vertically or to keep the length of choices about equal. Furthermore, the creation of these questions followed the recommendations from Technische Universität München [TU 12] to avoid a too high probability for guessing the right answer, e.g. by using single-choice most often with at least three answering choices.

[9] `https://www.audacity.de/`
[10] `https://www.techsmith.de/camtasia.html`

Figure 4.7: Part of the overview of a Learning Unit. This explanation is included in the introductory course.

To use the Learning Units, students have to register themselves on the Moodle platform. The different user names can later be distinguished in the Moodle logs. All entries in the registration process can be freely chosen, except for the use of an e-mail address that has to be working to complete the registration. It is not necessary to use an e-mail address of any university. Afterwards, students can use the introductory course.

Previous to each set of preliminary questions in all four Learning Units, a branch in the learning paths exists where students can immediately proceed to the respective content. Also, students can always choose to perceive content as text or video. These choices will not be discussed each time throughout the following sections.

4.5.1 Introductory Course

The main goal of the introductory course is to serve as a welcoming page for learners and to give a short overview of the usage of the Learning Units, as can be seen in Figure 4.7. The usage of the lessons and the learning paths are explained. The explanation comprises the possibility to choose the way of content presentation, as well as navigation inside the lessons. Additionally, the bonus pages and the hurdle for these are explained.

Links to the four Learning Units have been added when the studies were finished, previous to opening the Units to the public. Additionally, survey links and explanations related to the studies were removed.

4.5.2 Finite Automata and the Pumping Lemma

This first Learning Unit for FLAT consists of two blocks. The first block is concerned with deterministic finite automata and the pumping lemma. The basic notion of an automaton with different states is illustrated by the idea of a simple remote-controlled car. This car can either be turned on or off.

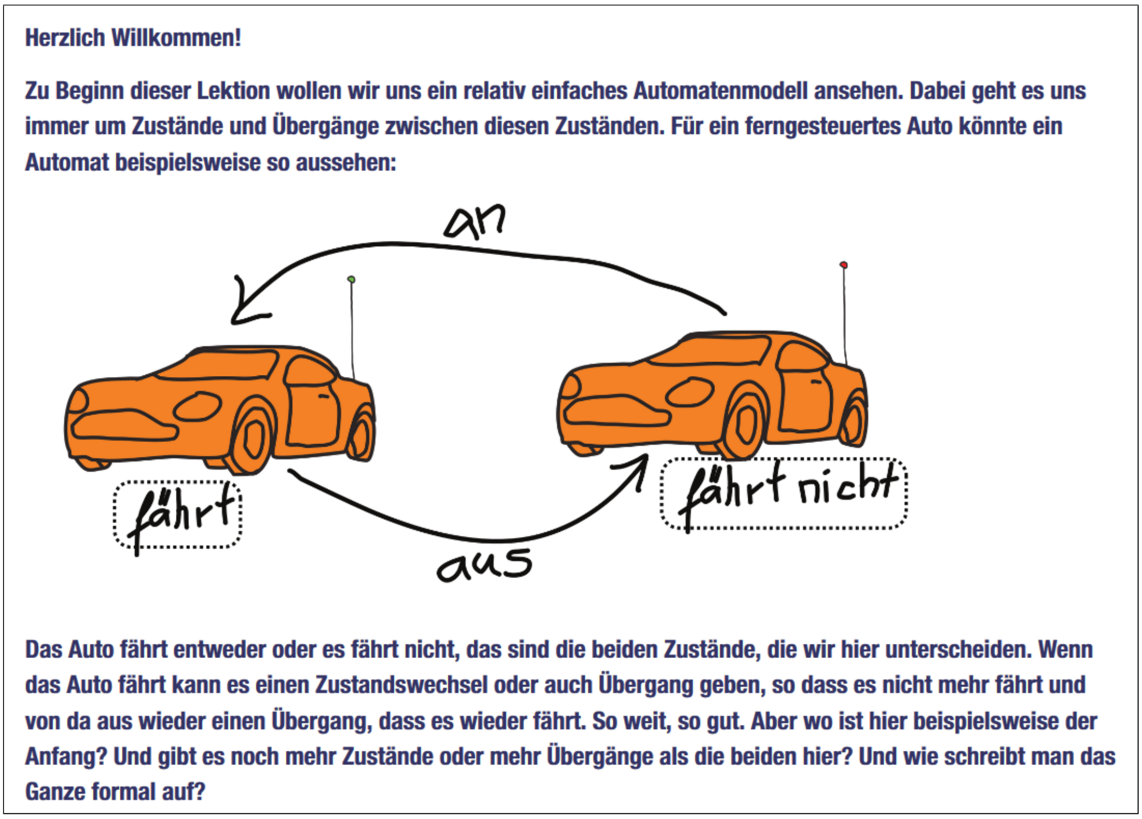


Figure 4.8: First introduction for students on the subject of automata.

Part of this introduction page can be seen in Figure 4.8. This gives students a practical view on states. These are one of the central abstractions used for automata. Students can now choose to answer preliminary questions leading to the next topic. In these preliminary questions, a simple automaton using only one state is presented with questions on possible meanings of state transitions. Students can get a first grasp how state transitions work. Alternatively, students can go directly to the explanation of DFAs, where they are also lead after answering the preliminary questions.

The explanation on this content starts with an intuitive example. Additionally, the formal notation is presented. Figure 4.9 shows part of this explanation, containing an example, where text was integrated with formal notation as well as with the depiction of an automaton. The notion of how an automaton reads parts of the alphabet Σ and accepts or rejects a word is presented, leading to the notion of languages accepted by an automaton. Afterwards, students can do first exercises on DFAs.

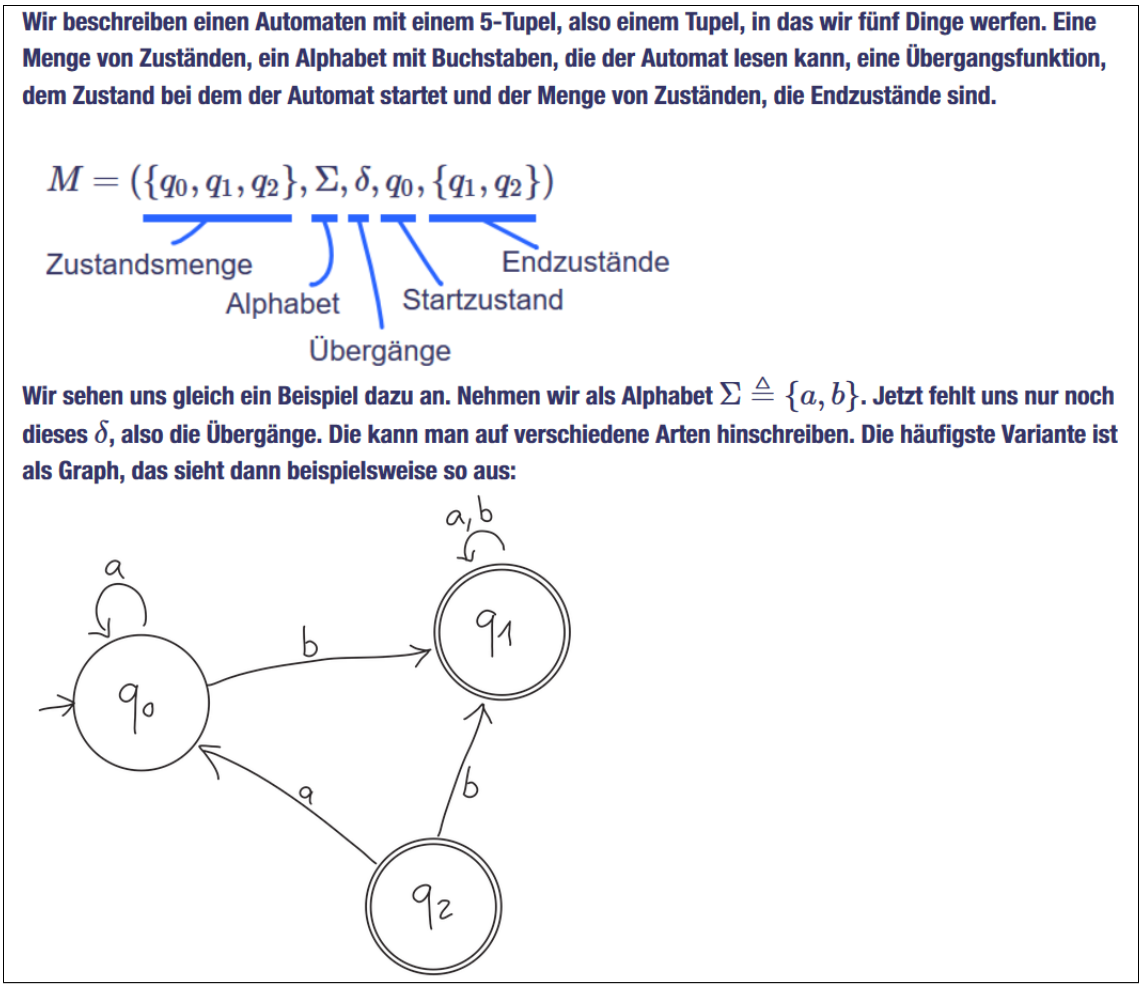


Figure 4.9: Part of the explanation of DFAs.

The first exercises present an automaton and a word. They pose the question whether the automaton accepts the word. Afterwards, different derivations of a word are presented for a given automaton, posing the question which one fits the automaton. To answer this, students need to understand how an automaton accepts words and how state transitions work. A derivation is the stepwise sequence of states in which the automaton reads a word, along with the information which parts of the word the automaton still has not read. Later, several questions about whether automata accept given languages are posed, to enable students to test their understanding of this notion as well.

On the following content page, a motivation is presented for the students to understand that not every language can be accepted by a DFA. Those languages accepted by a DFA are called regular. Now, students are about to learn a way to prove that a language is not regular, by use of the pumping lemma.

For the preliminary exercises, questions are posed on whether for a given language words of arbitrary length can be found and whether these words are still part of the given language. This is a vital part of the proof construction for the pumping lemma and therefore useful pretraining.

=== Nochmal die Formel ===

$\forall n \in \mathbb{N}. \exists w \in A.$

$(|w| \geq n \wedge$

$(\forall x, y, z \in \Sigma^*. (w = xyz \wedge y \neq \lambda \wedge |xy| \leq n) \rightarrow \exists k \in \mathbb{N}. xy^k z \notin A))$

=== Und ein typischer Beweis ===

Sei $n \in \mathbb{N}$ (beliebig aber fest).

[Hier lösen wir den Allquantor aus der Formel, die wir zeigen wollen, auf.]

Wir wählen das Wort $w = a^n b^n$ mit $w \in A$

[Den Existenzquantor, den wir zeigen müssen, lösen wir auf, indem wir ein konkretes Wort wählen. Wichtig ist hier, dass es an zwei Stellen von n abhängt und für alle n in der Sprache ist, sonst funktioniert der Beweis später nicht. Wenn man die Wahl hat ist es besser, wenn der erste n-große Block ganz am Anfang des Wortes steht, dann braucht man keine Fallunterscheidung.]

und $|w| \geq n$.

Figure 4.10: Part of the explanation of the pumping lemma.

On the content page on the pumping lemma, a motivation is given, followed by the (rather long) formula used for this lemma. Afterwards and step by step, this formula is used in the worked example of a proof to show students how to use this lemma. Part of the proof can be seen in Figure 4.10. Here, the formal notation of the lemma is split in colored parts. The proof is colored accordingly and enriched with additional explanations, to simplify reading. Afterwards, students can decide whether they want to start working on exercises or first read the extension of this content. The extension presents the intuitive relation between the pumping lemma and DFAs, for a better understanding of this lemma. The exercises on the pumping lemma mainly use partially completed examples of the pumping lemma to encourage students to read and understand part of a proof and decide on the next step. After this set of exercises, the lesson ends with a short overview. The 21 corresponding further exercises (the link is marked by a red checkmark, see Figure 4.1), are concerned with what kind of words a DFA accepts, what the accepted language is and how to derive a word state by state, whether the pumping lemma can be used for a given language, partially completed examples on the pumping lemma and a wrongly completed proof where students have to find the error. These exercises test understanding of the content in a variety of ways.

The bonus page for this first block refers students to the interactive theorem prover Isabelle/HOL to see how the pumping lemma is integrated in this theorem prover.

The second block of this Learning Unit is on non-deterministic finite automata and the powerset construction to transform an NFA into a DFA. It is of a very similar structure. The preliminary exercises on NFAs intuitively introduce, how an automaton can change to different states for reading the same letter. As this is the main difference in contrast to DFAs, emphasizing this aspect is helpful pretraining. The next content page introduces NFAs, and their differences to DFAs, and the following exercises revolve around this difference. The preliminary exercises on the next topic, the powerset construction, give an intuition how simple NFAs might relate to DFAs. The content page on the powerset construction uses a worked example to introduce this transformation, leading to the conclusion that every NFA can be turned into a DFA. The following exercises allow students to work on several examples for this construction. Students can choose the next step or check whether performed steps are correct. Again, the lesson ends after a short overview. The 16 corresponding further exercises are concerned with the accepted words of given NFAs, what the language of an NFA is, and abstract as well as concrete questions on the powerset construction, again using several times partially completed examples or completed examples with the question whether they are answered correctly.

The bonus page for this second block poses an open question on the differences between non-determinism in our automata model and randomness, as used on a homepage to generate random numbers based inter alia on atmospheric noise.

4.5.3 Minimization and Pushdown Automata

The second Learning Unit for FLAT is concerned with minimization and pushdown automata (PDA). It consists of one block for each of these topics. The first block contains one lesson on the Myhill-Nerode relation and one lesson on the table-filling algorithm.

The lesson on the Myhill-Nerode relation starts with an intuitive introduction to the relation, using the analogy of a cupboard (see Figure 4.11). The idea is again to have a practical example as a basis for an abstract structure – here equivalence classes. The preliminary questions prepare students to learn more about this relation by asking whether the extension of a given word with an arbitrary further letter would still be in a given language, which is a notion that is useful when learning more about the Myhill-Nerode relation to distinguish differences between the classes. The content page explains how the Myhill-Nerode relation sorts words into different equivalence classes and how this relation can be used to show that a language is regular if the relation has a finite number of equivalence classes.

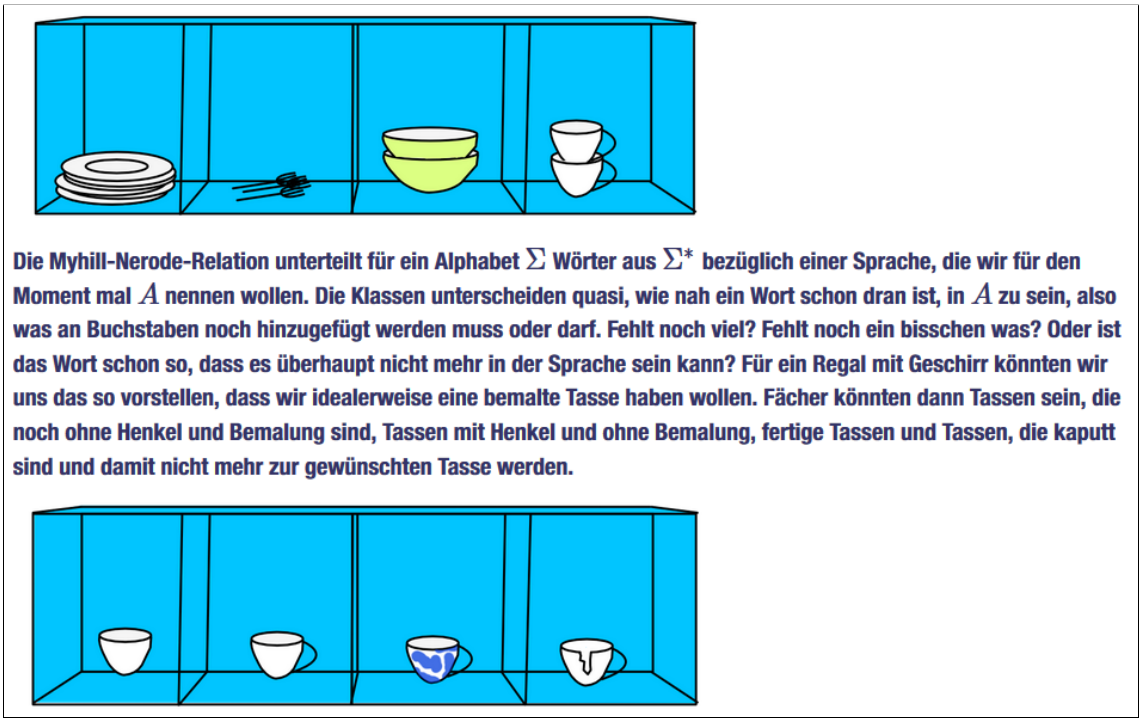


Figure 4.11: Part of the introduction of the Myhill-Nerode relation.

Additionally, it is explained that a language is not regular if the relation sorts the words of a language into an infinite number of equivalence classes. Both variants are presented by use of worked examples. The following questions are concerned with different words being in the same equivalence class for a given language and with supporting students' understanding of the equivalence classes by different examples for the finite as well as for the infinite case. For the infinite case, partially completed examples of the corresponding proof that a language is not regular are given. The lesson ends with a short overview.

The lesson on the table-filling algorithm starts with preliminary questions using simple automata and asking whether two states can be merged. The intention here is to give students a first intuition for redundant states considering the words an automaton accepts. The explanation of the table-filling algorithm uses a worked example to lead students through the algorithm step by step, filling the corresponding table and creating a minimized version of the original automaton. For one of the steps chosen as an example, see Figure 4.12. The following exercises repeat the steps of the algorithm by checking partially (sometimes wrongly) completed examples. The lesson ends with a very brief overview.

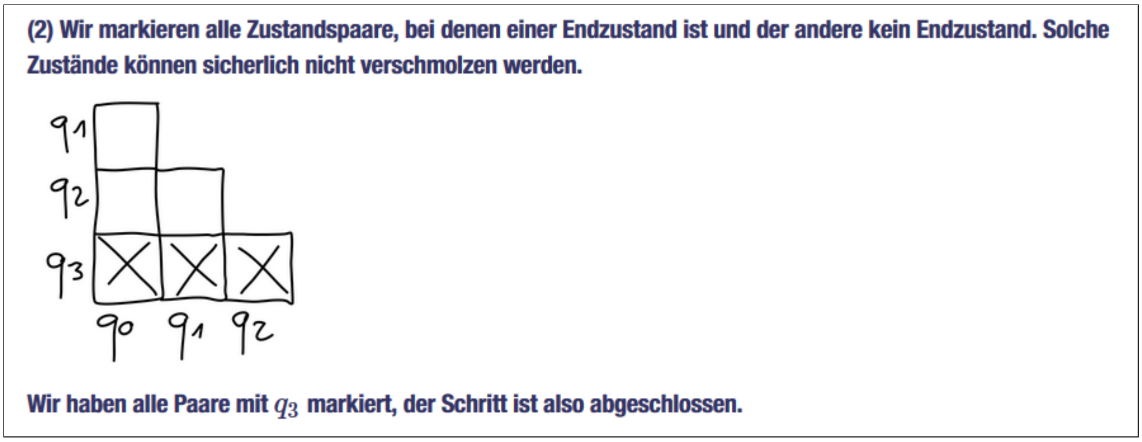


Figure 4.12: Part of the explanation of the table-filling algorithm.

The 17 further questions in this block are concerned with using both the Myhill-Nerode relation and the table-filling algorithm on partially completed examples or proofs, distinguishing for the Myhill-Nerode relation and whether a given language will lead to a finite or infinite number of equivalence classes.

The bonus page for this block poses the open question how the table-filling algorithm can be built in an object-oriented programming language.

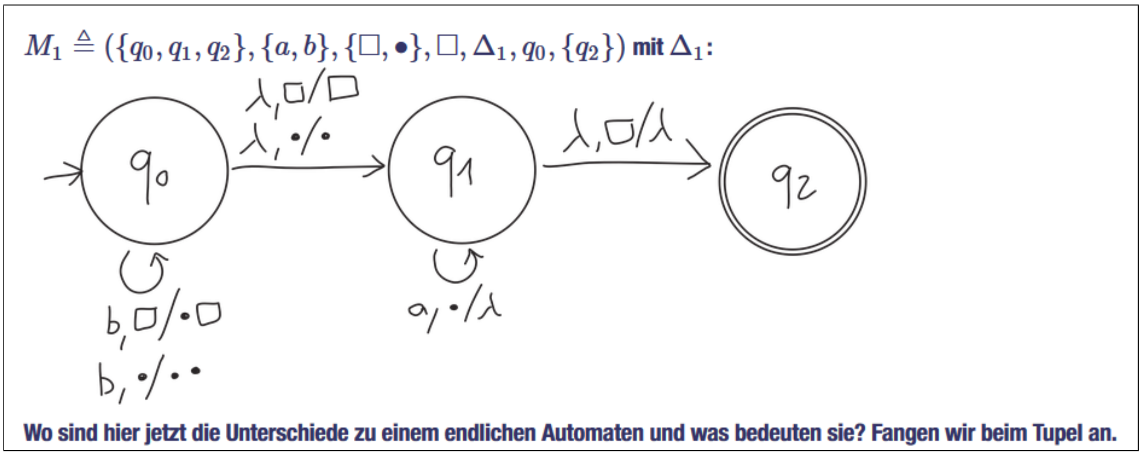


Figure 4.13: The beginning of the worked example for pushdown automata.

The second block, on pushdown automata, contains only one lesson. The preliminary questions on pushdown automata are concerned with slight changes to the automaton model of DFAs and whether that would be enough to accept a given language. Students can see here how simple changes in such models change what can be modeled. This is a relevant aspect of theoretical computer science. The content explanation presents PDAs and explains how words are accepted in this model and what the differences between the two accepting languages L_{Kel} and L_{End} are. This is again done by usage of a worked example, see Figure 4.13. Afterwards, students can decide whether they want to read an extension on this content – what a deterministic pushdown automaton (DPDA) is – or go directly to the exercises. The exercises are concerned with acceptance of words for PDAs, derivation of words and the acceptance of given languages.

Students can answer 11 further questions in this block. These questions are concerned with whether a language is accepted by a given automaton. Further questions are concerned with whether the automaton accepts certain words in which of the two languages – L_{Kel} and L_{End} – they are, and how words are derived in pushdown automata.

The bonus page for this second block poses the open question whether there is a regular language where the smallest DFA that accepts it has more states than the smallest pushdown automaton that accepts it.

4.5.4 Strong and Weak Bisimulation

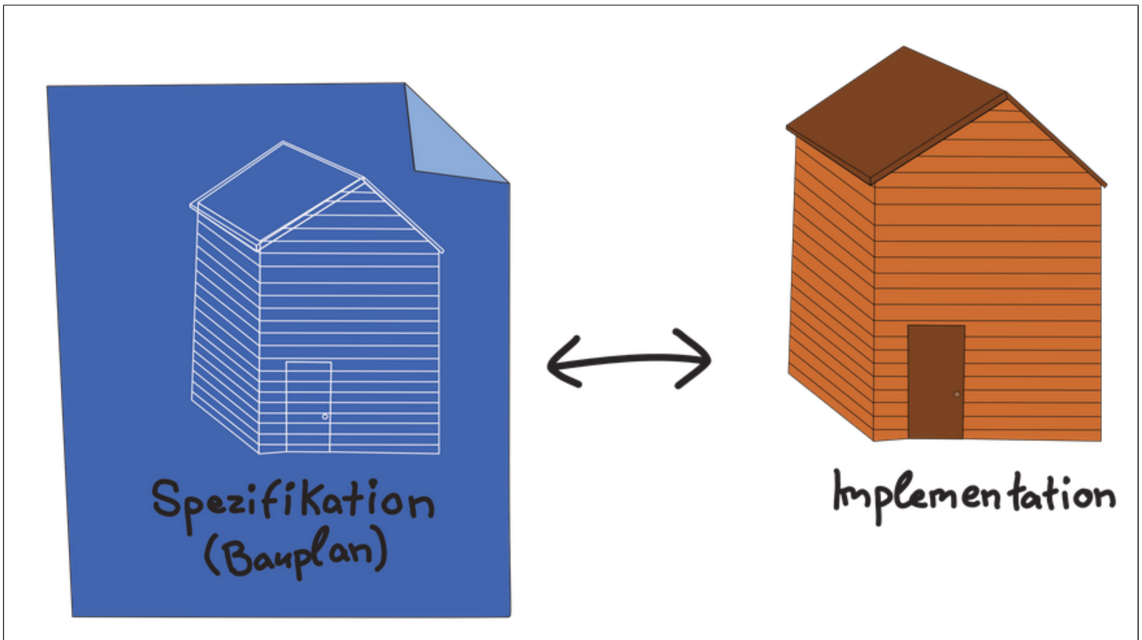


Figure 4.14: Graphical depiction of comparing a specification to its implementation.

In this Learning Unit, the first for ReSyst, the behavior of different processes is compared. The Learning Unit consists of three blocks.

The first block begins with explaining the idea of having the specification and implementation in one language in comparison to creating both in different languages, using the idea of constructing a house as an illustration, see Figure 4.14. In an extension of this content, students are shown that the use of such analogies can very easily be misleading.

This is done to prevent misconceptions if the students hold on to this analogy too severely. The next content page intuitively explains why comparisons of systems, in general, can be necessary and useful. Next, preliminary questions are posed, comparing simple processes based on the actions they can perform. As comparison of processes will be a central aspect of this Learning Unit, this is useful pretraining.

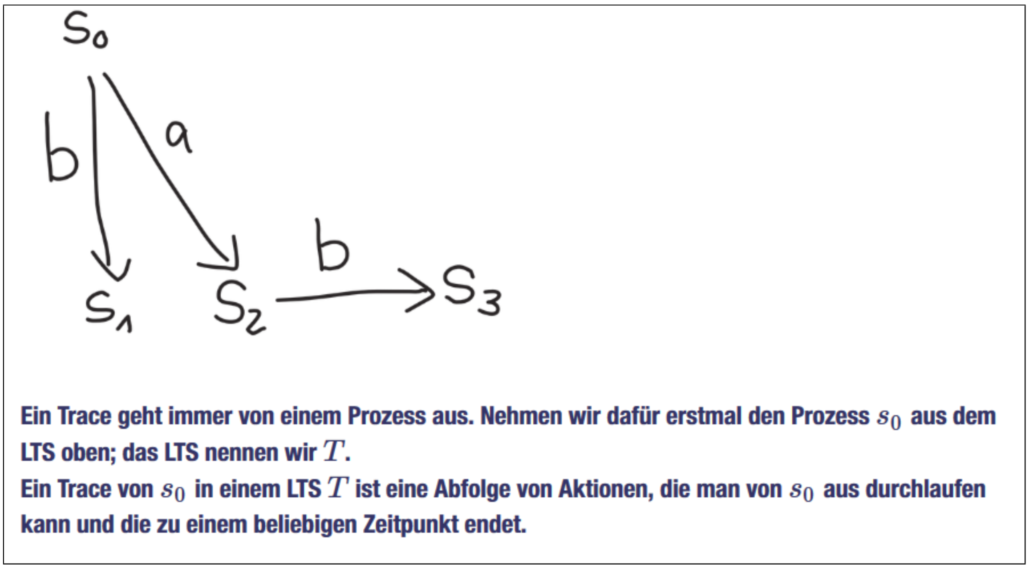


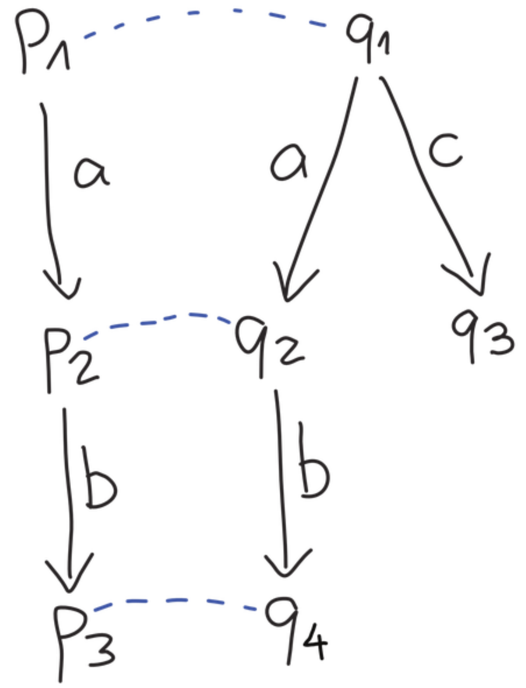
Figure 4.15: Part of the explanation on trace equivalence.

On the next content page, trace equivalence as a notion to compare processes in a labeled transition system is presented. A trace is basically a list of the actions done by a process in an execution. Part of this explanation can be seen in Figure 4.15. Students can now choose to see another extension, where other possibilities to compare processes (e.g. equality) are suggested and discussed briefly (and immediately discarded). In the following questions, students test their understanding, whether given traces are part of the traces of a process and what the traces of a given process are. The lesson ends with a brief overview.

Students can answer six further questions on trace equivalence. These questions are concerned with a list of given words. For this list, students are asked the question which of these words are in the traces of a process and whether two given processes have the same traces.

The bonus page for this block presents students with an LTS and an NFA. Students are asked to compare the traces of the former to the accepted language of the latter. Thereby, students can relate their knowledge of LTSs to their FLAT knowledge.

The second block, on strong bisimulation, contains two lessons. The first of the lessons starts with an explanation of the shortcomings of trace equivalence. This notion does not include communication in-between processes. The preliminary questions for the next content part, strong simulation, always give students two processes and ask whether one of these processes can imitate everything the other process can do.



p_1 kann nur ein a gefolgt von einem b. Das kann q_1 nachmachen, indem es die a-Aktion zu q_2 ausführt. Die andere a-Aktion brauchen wir bei dem der nachmacht nicht weiter zu beachten. Von q_2 aus folgt dann die b-Aktion zu q_4. Die Paare von Prozessen, die jeweils Original und Nachmacher sind, werfen wir in eine Menge, die sogenannte Simulationsrelation. Hier wäre das:

$$\mathcal{R} = \{(p_1, q_1), (p_2, q_2), (p_3, q_4)\}$$

Figure 4.16: Part of the explanation on strong simulation.

On the next content page, strong simulation is explained (see Figure 4.16), based on this idea of one process imitating the other. The corresponding simulation relation is introduced. The following questions are concerned with which processes can simulate each other for given LTSs. For a given wrong simulation relation, students are asked which of the pairs in the relation have to be removed or which pairs have to be added to make it a correct solution. Here, students learn typical mistakes in the creation of such relations. This focuses their attention to avoiding these mistakes. On the next content page, a brief motivation is given why simulation is still not the ideal way of comparing processes. The next set of preliminary questions also hand students two processes, but now the question is which processes are able to do the same, whatever that means in this context. Here the intuition students should get is mainly to question different ways of comparing behavior. On the next content page, strong bisimulation is explained, where processes can do the same actions. The corresponding bisimulation relation is introduced. In the following questions, for given LTSs, students are asked which processes are bisimilar, respectively. Additionally, students are given an LTS and a bisimulation relation. They are asked whether this is the correct relation to show that two processes are bisimilar and whether two bisimilar processes stay bisimilar if the LTS is transformed in certain ways. Afterwards, students can choose to work on more complex exercises or read another content extension, arguing why bisimulation is an equivalence relation and, even further, why it is a congruence relation. After a brief summary, this lesson ends.

- **Betrachte $(p_1, q_1) \in \mathcal{R}$**

  Transitionen in p_1:

  - Für $p_1 \overset{a}{\to} p_2$ wähle $q_1 \overset{a}{\to} q_2$ und $(p_2, q_2) \in \mathcal{R}$

[Da p_1 nur diese eine Transition hat sind wir mit dem ersten Paar schon fertig. Das resultierende Paar (p_2, q_2) ist ebenfalls in der Relation, also hat auch alles geklappt wie gewünscht. Weiter mit dem nächsten Paar.]

- **Betrachte $(p_2, q_2) \in \mathcal{R}$**

  Transitionen in p_2:

  - Für $p_2 \overset{b}{\to} p_3$ wähle $q_2 \overset{b}{\to} q_4$ und $(p_3, q_4) \in \mathcal{R}$

[Auch das Paar wäre geschafft und wieder ist das resultierende Paar in $\mathcal{R}$. Auf zum letzten Paar.]

- **Betrachte $(p_3, q_4) \in \mathcal{R}$**

  Transitionen in p_3:

  Keine Transitionen in p_3 möglich.

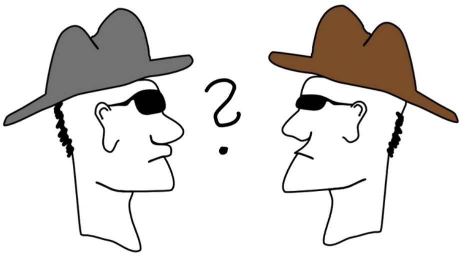
Figure 4.17: Part of the explanation on proving that one process simulates the other.

The second lesson in this block is concerned with proving that one process simulates another or that two processes are bisimilar, using the respective relations. Using a worked example, the content explanation on those proofs for strong simulation presents the proof step by step, along with explanations on each step, see Figure 4.17. In the following exercises, partially completed examples present proofs with missing lines. Students can then choose how to amend these proofs. The aim of these tasks is to deepen their understanding of those proofs, but also their ability to read these proofs faster and understand the schematic structure. On the following content page, building on the previous explanation, the proof that two processes are bisimilar is explained, again based on a worked example. In the following exercises, students can choose the correct bisimulation relation for two processes in a given LTS, and again, amend proofs. The lesson ends with a brief overview. In this lesson, no preliminary questions are used, as these proofs are complicated to introduce in an intuitive notion.

Students can answer 13 further questions in this block, concerned with adding the correct line to a proof as a partially completed example, checking or changing simulation and bisimulation relations, and assessing which relations hold for two processes.

The bonus page for this block is concerned with using the tool PseuCo[11] to display a given process, asking the students additionally to find a bisimilar one.

Es kann für die Betrachtung aber durchaus einen Unterschied machen ob wir immer mitbekommen, dass Kommunikation passiert oder ob nicht. Damit wir ein besseres Gefühl dafür kriegen, stellen wir uns mal zwei Geheimagenten vor, die miteinander kommunizieren.



Dabei kann man sich leicht Szenarien vorstellen, bei denen es nicht nur problematisch ist, wenn die genauen Informationen, die hin- und hergeschickt wurden, ans Tageslicht gelangen, sondern auch solche, bei denen es schon Probleme gibt, wenn klar wird, dass überhaupt kommuniziert wurde.

Idealerweise sollte eine solche Art Prozesse zu vergleichen, bei der wir von τ-Aktionen abstrahieren dieselben tollen Eigenschaften haben wie starke Bisimulation. Leider wird das nicht für alle Eigenschaften gelten.

Figure 4.18: Part of the introduction of weak transitions by explanations on hiding secret communication.

The third block in this Learning Unit strongly builds upon the content of the previous block. The previous block already introduced the notion of τ-transitions to hide what exact communication has happened between processes. In the first content page, the idea of hiding some of the process behavior is deepened further. The idea is to also hide the τ-transitions in order to hide that any communication has happened between processes, using the analogy of agents communicating secretly, see Figure 4.18. The following preliminary questions concentrate on different actions of processes, to motivate which behavior is useful to be hidden and which might be problematic. The content page on weak simulation introduces the so-called weak transition and explains the differences between strong and weak simulation using these weak transitions. These explanations again use a worked example to introduce these notions as practically as possible. The questions on this content are concerned with checking whether a given process weakly simulates another, and with checking for two processes how a weak simulation relation has to be changed to be correct. Following these content questions, preliminary questions on weak bisimulation are posed. Again, these questions intuitively compare processes on whether their behavior is equal

[11] https://pseuco.com/

if τ-transitions are hidden. On the next content page, weak bisimulation is explained by a worked example. This builds upon the strong bisimulation as well as the already introduced weak transitions and weak simulation. In the following questions, processes are compared concerning the relations that hold for them – strong or weak bisimulation – and how given relations have to be changed to create correct weak bisimulation relations. The following content page gives an overview how the proofs showing that two processes are weakly similar or bisimilar have to be changed in comparison to strong simulation and bisimulation. An extension to this content page explains why weak bisimulation is again an equivalence relation but no congruence. The lesson ends with a brief overview.

Students can answers 12 further questions in this block, concerned with amending proofs on weak simulation and bisimulation, checking which relations hold in-between two processes including both weak and strong simulation and bisimulation, and changing relations to create correct weak simulation or weak bisimulation relations.

The bonus page poses the open question to students why we work so much on τ-transitions in the first place instead of just ignoring them if we want transitions to be hidden.

4.5.5 Fixed Point Theory

The second Learning Unit for ReSyst, on fixed point theory, consists of four blocks, as this is the most intuitive way to split the content. Concerning the amount of content, the first two blocks might as well have been created as one block.

The lesson in the first block starts with a short overview, leading to the preliminary questions that use simple examples to introduce the idea of functions where, for some inputs, the output is equal to the input. On the following content page, fixed points are introduced, using different printers as an analogy, see Figure 4.19. The following questions present students with different functions and pose questions on what their fixed points are and how many fixed points these functions have. The lesson ends with a brief overview.

Students can answer six further questions in this block, concerned with revising the notion of fixed points, especially what the fixed points of certain functions are and what the input and output of given functions can be.

The bonus page on the first block is concerned with a visualization tool on the homepage GeoGebra[12], asking students to change the parameters for a function in a way that the function has no, one, or three fixed points.

[12] `https://www.geogebra.org`

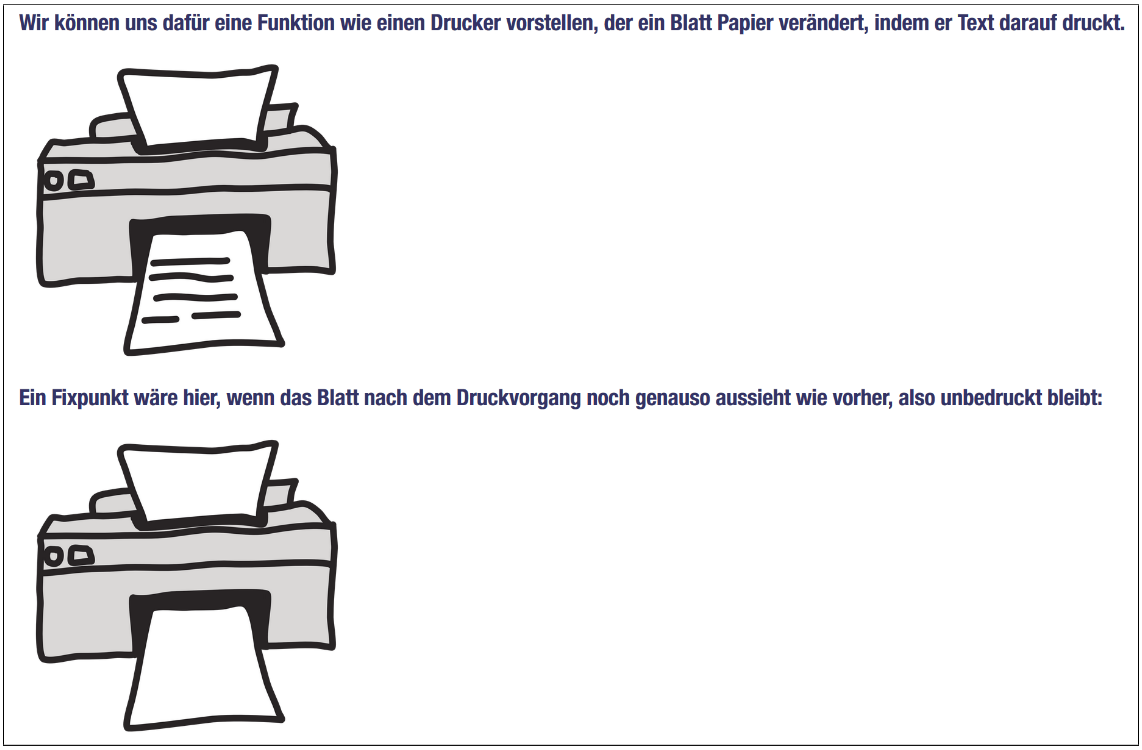


Figure 4.19: Part of the introduction of fixed points using printers as an analogy.

The second block introduces partially ordered sets, upper and lower bounds, lattices and monotonous functions. All these are mathematical concepts some students might already know, but these are necessary for the theorems in the third block and therefore are presented here. The block contains two lessons.

In the first lesson, after a brief introduction, preliminary questions are posed on which elements of given sets are larger than others and what being a larger element could mean. Afterwards, a content page introduces the notion of partially ordered sets and their properties, see Figure 4.20. The following questions ask students to compare relations, to find out which one creates a partially ordered set in combination with a given set, and to determine for a given partially ordered set which of the given elements is larger than another.

In the following preliminary questions, the idea of elements that are larger or smaller than all other elements is introduced by simple examples, to find such an element in a given structure. The next content page uses a worked example to introduce upper and lower bounds, and the following exercises pose questions on, whether, for given settings, such bounds exist or to choose what they are from a variety of sets, or elements. The lesson ends with a brief overview and a link where students can find a screencast with more information on these topics.

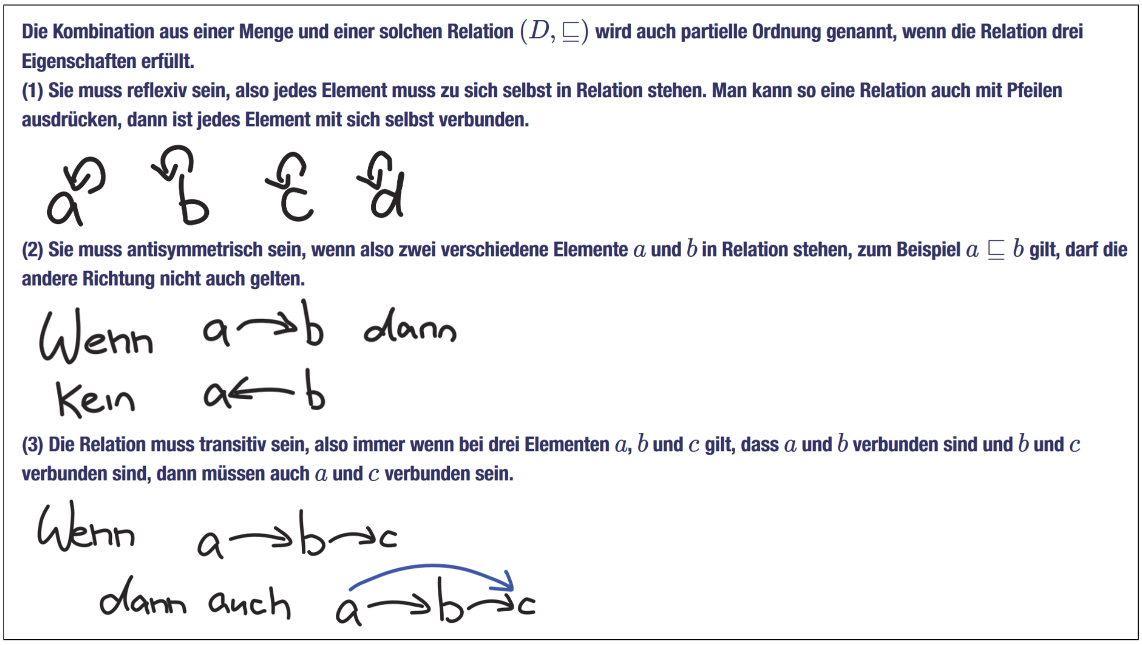


Figure 4.20: Part of the introduction of partially ordered sets.

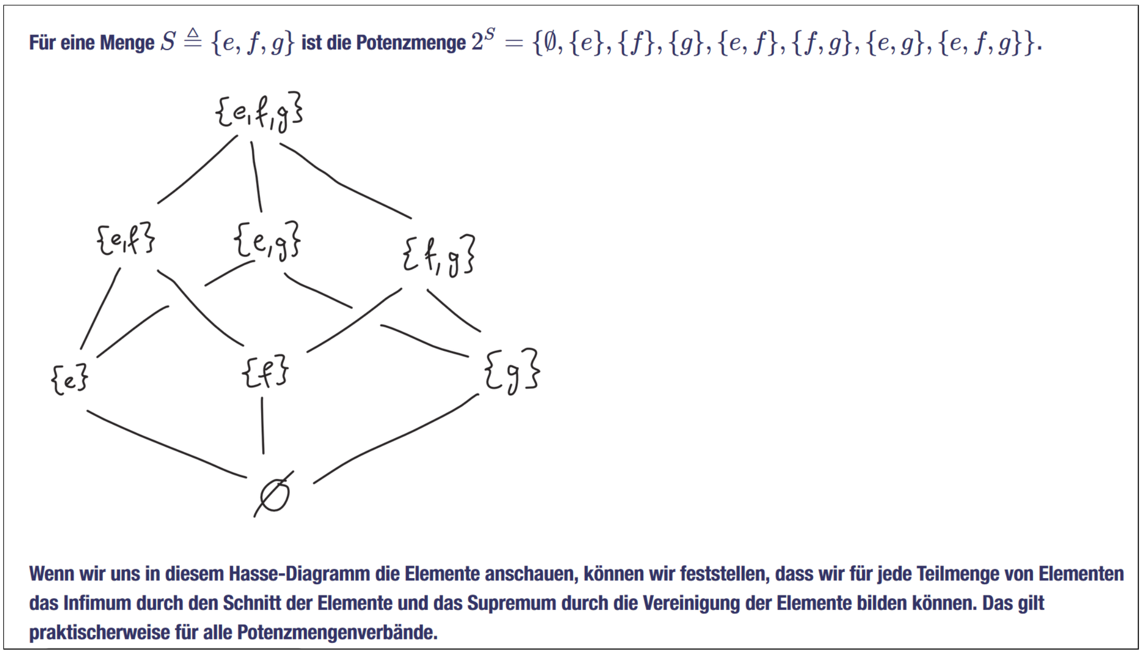


Figure 4.21: Part of the introduction of lattices.

The second lesson again starts with a brief introduction, followed by preliminary questions introducing different partially ordered sets where sometimes elements can be compared on which one is larger, and sometimes such a comparison is not possible. This leads up to the idea of a lattice. On the next content page, lattices and complete lattices are introduced (see Figure 4.21) along with the idea that for a set S, the lattice $(2^S, \subseteq)$ is always a complete lattice[13]. This idea will be useful in the following block for students.

[13] 2^S is the powerset of S

The following questions are concerned with determining whether given pairs are lattices or complete lattices or none of both, determining upper and lower bounds for given pairs, and generally deepening the students' understanding of bounds and lattices by use of examples. The following preliminary topic is rather different to the preceding content. Two elements in a given setting are presented and how their relation changes after a given function is applied on both, leading to the definition of monotony. On the following content page, monotony is explained for functions in this scenario. The idea is that whenever two elements are related, and a monotonous function is applied to both, the elements still are related. The following questions are concerned with changing a function in a way that it is monotonous afterwards and determining whether given functions are monotonous. The lesson ends with a brief summary.

Students can answer seven further questions in this block, concerned with determining upper or lower bounds for a given setting, comparing different tuples to find which one is a lattice or partially ordered set, determining which of several given functions are monotonous, or finding the smallest element of a given lattice.

The bonus question is concerned with a possible extension of lattices with infinite sets by a largest element.

Dann nennen wir $\{d \in D | f(d) \sqsubseteq d\}$ die Prä-Fixpunkte von f.
Passend dazu nennen wir $\{d \in D | d \sqsubseteq f(d)\}$ die Post-Fixpunkte von f.
'Prä-' beschreibt meistens etwas vorangestelltes und 'Post-' etwas was danach kommt. Die Zuordnung kann man sich hier merken, weil bei den Prä-Fixpunkten das $f(d)$ vor dem $\sqsubseteq$ kommt und bei den Post-Fixpunkten danach.

Figure 4.22: Part of the introduction of pre-fixed points and post-fixed points.

The third block is concerned with the computation of fixed points. The corresponding lesson starts with a content page to present students with the notion of pre-fixed points and post-fixed points (see Figure 4.22), which is further illustrated by a worked example. This introduction is followed by exercises, where the students have to determine what the pre-fixed points or post-fixed points are for a given setting. The preliminary questions for the next block pose very similar questions to those before, which consist of two repeating scenarios, leading students to the conclusion that here, the actual fixed points are contained as well in the pre-fixed points as in the post-fixed points.

Afterwards, Tarski's fixed point theorem is introduced. It states that in a complete lattice with a monotonous function, a least and a largest fixed point always exist (being the least upper bound of the post-fixed points and the greatest lower bound of the pre-fixed points, respectively), illustrated by the use of two examples. The extension of this content page outlines the idea on how to prove this theorem. The following questions revise parts of the theorem to test whether students can use this correctly and ask students to apply the theorem. Next, Tarski's and Knaster's theorem to compute fixed points is introduced. This theorem states that for the case of a finite complete lattice and a monotonous function, the least and largest fixed points can be computed, by taking the smallest (or largest) element of the lattice and applying the function repeatedly until a fixed point is reached. This is again illustrated by use of an example, see Figure 4.23. In another content extension, students can read more about the idea how to prove this theorem. In the following questions, similar to the previous theorem, parts of the theorem are revised, and students are asked to compute the next step in a given setting towards a least or largest fixed point.

Das Supremum eines Potenzmengenverbands ist immer die Menge selbst, also hier S, das Infimum ist immer die leere Menge.
Bestimmen wir den größten Fixpunkt:
$g^1(S) = \{1,2\} \cup \{2\} = \{1,2\} = S.$
Da hier das Ergebnis direkt bei der ersten Iteration gleich der Eingabe ist, haben wir schon den größten Fixpunkt erreicht. Probieren wir es mit dem kleinsten Fixpunkt.
$g^1(\emptyset) = \emptyset \cup \{2\} = \{2\}.$
$g^2(\emptyset) = g(g(\emptyset)) = g(\{2\}) = \{2\} \cup \{2\} = \{2\}.$
Da in der zweiten Runde das gleiche Ergebnis herauskommt wie in der vorherigen Runde haben wir wiederum einen Fixpunkt erreicht. Das ist der kleinste Fixpunkt von g.

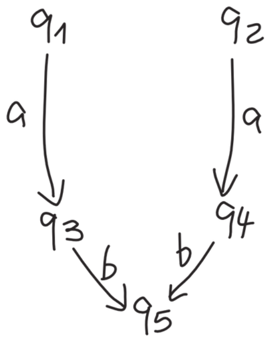
Figure 4.23: Part of the introduction of Tarski's and Knaster's fixed point theorem.

Students can answer 15 further questions in this block. Most of these questions are partially completed examples, where students are asked to determine the next step of the fixed point computation, choose the correct pre-fixed points or post-fixed points in a given setting, and revise the theorems that were presented in the lesson.

The bonus page, in this case, is not a question or task but briefly presents the students with an idea of who this man called Alfred Tarski was, whose last name they use in the theorems all the time.

The lesson for the fourth and last block starts with an introductory text. It gives an intuition how the largest bisimulation – the bisimilarity – could be computed as a fixed point. The preliminary questions here give further intuitions concerning bisimulation, fixed points and monotonous functions, using simple examples. In the following content explanation, the function $\mathcal{F}$ is introduced and explained. It can be used to compute the bisimilarity as a fixed point for a given LTS. This computation is further illustrated by the use of two worked examples. One of them can be seen in Figure 4.24. A content extension explains more about why the assumptions of Tarski's and Knaster's fixed point theorem that we use for the computations are fulfilled. The following questions revise parts of the theorem, and students are asked to compute steps in partially completed examples towards bisimilarity.

Probieren wir es noch einmal mit einem weiteren kleinen LTS:



Wieder landen im ersten Schritt alle Paare im Ergebnis, die die gleichen Aktionen können.

$\mathcal{F}(\text{Proc} \times \text{Proc}) = r(s(\{(q_1, q_2), (q_3, q_4)\}))$

Berechnen wir eine weitere Iteration.

$\mathcal{F}^2(\text{Proc} \times \text{Proc}) = r(s(\{(q_1, q_2), (q_3, q_4)\})) = \mathcal{F}(\text{Proc} \times \text{Proc})$

Sowohl (q_1, q_2) als auch (q_3, q_4) landen mit ihren Aktionen wieder bei Paaren, die im Ergebnis der vorherigen Aktion waren, sie landen also auch diesmal im Ergebnis. Damit ist das Ergebnis gleich zur vorherigen Iteration und wir haben einen Fixpunkt erreicht.

Figure 4.24: An example on the computation of bisimilarity as a fixed point.

Students can answer eight further questions in this block, concerned with revising the assumptions to apply the fixed point theorems and parts of the theorems themselves. Additionally, partially completed examples are used just as in the lesson, where students are asked to compute the first or next step towards bisimilarity.

The bonus page for this block poses the open question what function different to the $\mathcal{F}$-function would be necessary to compute the smallest bisimulation for a given LTS.

Chapter 5

Evaluation

Up to this point in the dissertation, the motivation for the research was described, the research questions were derived, and the theoretical background was discussed, based on cognitive theories, learning styles and existing work in this research area. Afterwards, the intended learning outcomes and the general concept of the Learning Units were discussed, alongside the implementation of the Learning Units. The concept and its implementation constitute main contributions of this work. In this chapter, a description of the settings of the studies is given, followed by the second main contribution, the discussion of the corresponding evaluation instrument. The structure of the studies will be described in detail, as well as the used questionnaires, followed by a discussion of problems with low participation in the studies.

5.1 Setting

This section will describe the setting of the evaluation. As already mentioned in Section 4.1, 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: One course on formal languages and automata theory (FLAT), and one on reactive systems (ReSyst), mainly on the modeling of processes and how fixed points can be used to compute properties of such models.

The FLAT studies were conducted in:

- the course “Formale Sprachen und Automaten” at Technische Universität Berlin in the winter semester 2017/2018,

- the course “Automaten und Formale Sprachen” at Universität Duisburg-Essen in the summer semester 2018 and
- the course “Theoretische Grundlagen: Modellierungskonzepte der Informatik” at Universität Potsdam in the winter semester 2018/2019.

All of these courses were part of bachelor degree programs.

The ReSyst studies were conducted in:

- the course “Concurrency Theory” at RWTH Aachen University in the winter semester 2017/2018,
- the course “Reaktive Systeme” at Technische Universität Berlin in the summer semester 2018 and
- the course “Theoretical Computer Science” at Universität Salzburg in the summer semester 2018.

The course in Berlin is part of the bachelor degree program, the courses in Aachen and Salzburg are each part of a master degree program. All three courses strongly rely on the same textbook by Aceto et al. [AILS07] for this topic, which led inter alia to the choice of these courses for the studies.

The FLAT course in Berlin started with about 600 students, the courses in Duisburg-Essen and Potsdam both with about 250 students. The ReSyst course in Berlin started with about 100 students, the one in Aachen with about 20 students, and the course in Salzburg with about 10 students.

The “classic” materials students can learn with in these courses are slides, formularies and textbooks, as can e.g. be seen by the course homepages for the courses in Duisburg-Essen [Unib], Salzburg [Unif] and Aachen [RWTa].

The Learning Units use videos, animations, texts, images and exercises to present the same content as the learning material mainly used in the corresponding course. For the FLAT course in Berlin, the material was a formulary and digital notes, in Duisburg-Essen and Potsdam slides. For ReSyst in Berlin, the learning material was a formulary and the corresponding textbook, for the courses in Aachen and Salzburg it was mainly the textbook and slides.

As can be seen in Section 2.1.2, tool-based approaches exist, but apart from JFLAP and FLACI they hardly seem to be maintained anymore. Typical exercises in courses on theoretical computer science are paper and pencil exercises, as can be seen from the aforementioned course homepages as well as from different sources (e.g. [CFR04], [RBFR06], [Ver05], [VVV04]).

5.2 Description of the Preparation

This section will give a brief overview of important steps in the process of preparation for the studies. As described in Section 4.2.1, the Learning Units were evaluated by instructors, assistants and students. For the students' evaluation, messages were posted on the discussion board of one already finished FLAT course at Technische Universität Berlin, where a great number of students still had a subscription, and the discussion board of another computer science course. This seminar, called "The Software Horror Picture Show" is typically attended in the sixth semester. Four students finally participated in this preliminary study. The research approach was described very briefly, and students were asked to help in testing the Learning Units and questionnaires. Four students attended these tests, talking about their thoughts and processes while using the Learning Units, and filling out the questionnaires. This was monitored by the author and led to changes of the wording of some items in the Learning Units. Also the lesson graphs were added for a better overview. Other research assistants had already asked for such an aid when testing the Learning Units. These student tests also gave an interesting first insight into the target group and how they reacted to the Learning Units, which seemed in line with the intentions of the approach.

Additionally, the data protection official of Technische Universität Berlin was consulted, to prevent problems with data protection for the students. The approach was generally approved of, as it was in fully pseudonymized form. It was noted that if students were asked for their grade range in questionnaires – which was intended as part of additional surveys after the actual studies, with grade ranges instead of actual grades, to prevent direct identification – the grade ranges had to be defined after exams were graded. Grade ranges independent of the actual exam grades carried the risk that, by coincidence, a direct identification would be possible, e.g. when a grade range contained only one student. This idea was later implemented in the studies.

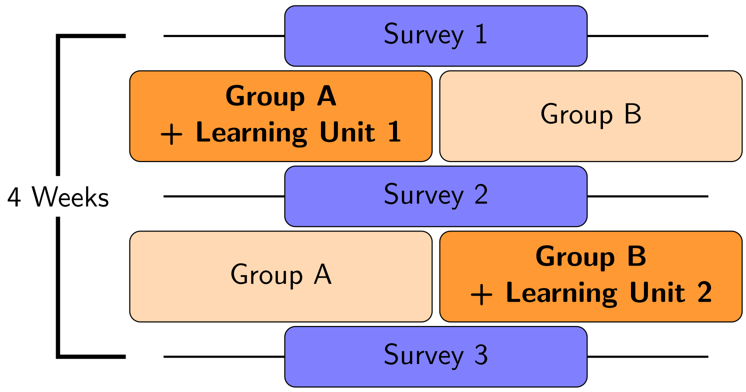


Figure 5.1: The general structure of each of the six studies.

5.3 Structure of the Study

This section will present the structure of the studies and details on how they were conducted. For the studies, a cross-over design – specifically a repeated measures design with counterbalancing – was chosen. As can be seen in Figure 5.1, which illustrates the general design for each study, at first survey 1 was conducted with all students that wanted to participate, then the students were separated in two groups A and B. The factors of this group separation will be discussed later in this section. Now, group A was enabled to use the first Learning Unit for this course for about two weeks. Meanwhile, the course went on unchanged, therefore group A had access to the Learning Unit and the corresponding university course, whereas group B only had the university course with its usual possibilities and material. After two weeks, the first Learning Unit was closed again. After this, survey 2 was conducted with both groups, inter alia testing whether there existed differences in-between the groups. Following survey 2, group B was enabled to use the second Learning Unit for this course for two weeks. Afterwards, the Learning Unit was closed again and survey 3 was conducted, again testing for differences in motivation and competencies.

In the two largest studies, the ones in Berlin, additional follow-up surveys were conducted after the study was finished, posing questions on the students' grade ranges to compare these to the grade ranges for the whole course, and on students' usage of the Learning Units. For the period after the study, the Learning Units both were opened for all respective participants.

The main reason for this choice of study structure was to reduce the effects of ordering, i.e. taking a certain group as test group and the other as control group. This systematic bias is described extensively by Field [Fie17]. An additionally useful aspect of this was that no participant was "only" part of a control group, which might have frustrated students.

In all studies, the approach was used as a supplement. All courses remained unchanged.

To further motivate students, Amazon vouchers were raffled between all participants that filled out all three surveys. After the first study in Aachen and low participation there, students were additionally offered the opportunity to use both Learning Units for their exam preparation if enough students participated. In all further study locations, the Learning Units were opened to all participants after the study had been finished.

The surveys themselves were to be filled out on the platform SoSci survey[1], which is a German platform for surveys that is free for research purposes. As will be presented further in Section 5.4, students were asked to create a pseudonym for themselves based on several simple questions. To link their answers on SoSci survey to their Moodle profiles, students were additionally asked to fill out a short survey on Moodle containing only the questions for the pseudonym. This combination was chosen as the creation of surveys and the data export on SoSci survey worked considerably simpler and better than directly in Moodle. However, this was possibly not the ideal choice, as students that only filled out the (more important) survey on SoSci survey and forgot to fill out the Moodle survey in time could not be considered for the study.

After the initial survey 1 and the survey on pseudonyms in Moodle, the pseudonyms were matched. All data sets that could not be matched were not evaluated further. Section 6.1 explains how pseudonyms were handled that were not equal but very close.

Afterwards, all remaining participants were separated into two groups A and B. As it was not probable that enough students would participate to allow for genuinely random group separation, the groups were separated and balanced out manually. The factors of this separation in decreasing order of importance were:

- Sex
- Repeater
- Study program
- Competencies
- Learning alone or in groups
- Self-regulated learning
- Motivation

[1] `https://www.soscisurvey.de/`

Sex was balanced out first between the groups, to balance out potential gender differences. Repeaters were balanced out, as it was assumed that they were part of a slightly different population than the actual target population of the study and would later be factored out. Additionally, the study program (e.g. bachelor of computer science, bachelor of mathematics or the faculty's orientation program) was balanced out, the results on the students' preliminary and basic knowledge, their interest in learning in groups, their interest in self-regulated learning, and their learning motivation. Learning styles were assumed to be the next factor beneath motivation, but this was never used due to the many dimensions.

To reduce the so-called non-response error[2], the author presented the study personally in all locations, precipitated by the low participation rates in Aachen. In Aachen, the study was presented by the professor. Further information was put up on the homepage as well. In all other locations and in addition to the personal presentation in the lecture, messages were sent via the discussion board or posted on the course website. In the lectures, sheets with information on the study and QR codes to the surveys were distributed. These sheets and messages also contained the link to the Moodle introduction course for the respective study, which explained the research approach in more detail and presented the concrete dates of the study phases. The Learning Units were not altered in-between the different settings except for these dates in the introduction course and basic definitions in the FLAT courses. For these courses, most of the students were at the beginning of their study programs. To prevent confusion for the students, the order in which the elements are listed in automata definitions was altered. These definitions were adjusted to the definitions used in the respective university course. For the same reason, either λ or ϵ was used for the so-called empty word in a formal language. As these respective definitions can be used interchangeably, this could be done without further reworking the Units.

It was not possible to make sure that there were no exchanges in-between participants. Therefore, results have to be considered in this context.

5.4 Survey Structure

The following section will present the structure of the surveys used for all six studies in an exemplary fashion, as the surveys only differed in-between FLAT and ReSyst surveys, concerning the respective questions on content. For all surveys, one exemplary questionnaire can be found in the appendix (survey 1: Appendix E.1, survey 2: Appendix E.2,

[2]Bortz and Döring describe this error as the difference between possible participants and those actually participating. In the studies this is the difference between course participants and study participants. [DB16]

survey 3: Appendix E.3, follow-up survey: Appendix E.4). Both for FLAT and ReSyst respectively, all questionnaires for one exemplary study can also be found in the digital appendix (Appendix A-QU507).

5.4.1 Survey 1

The first survey started with a short introductory text on the survey, telling students its basic aims, the probable duration of this survey (20 minutes), and asking them to please answer the texts truthfully. Additionally, students were assured that the data would be used in an anonymized way and for research purposes only, without influencing their grading in the university course. The students were also kindly requested not to guess on the questions but when in doubt, rather to use the alternative "I do not know" option.

The next part started with a self-constructed questionnaire that was built based on existing questionnaires. The most influential of these questionnaires were:

- Motivated strategies for learning questionnaire (MSLQ) [DPSM15]
- Inventar zur Computerbildung (INCOBI) [RNG01]
- Lernstrategien im Studium (List) [SW09]

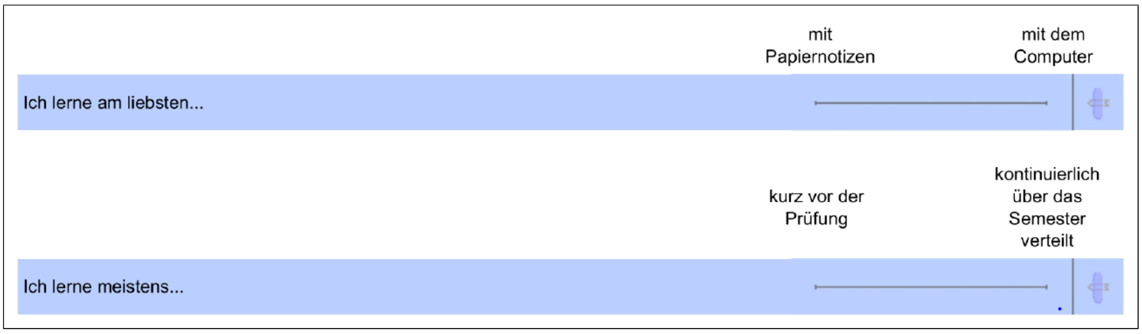


Figure 5.2: An example of the self-constructed first questionnaire in survey 1.

The aim of this short questionnaire was to measure general learning tendencies, the affinity to computers, the affinity to learning management systems and the abilities for self-regulated learning. For example items, see Figure 5.2. This questionnaire was used to get more information on how the students learn. The questionnaire was self-constructed, as existing questionnaires either had too many items or did not include all concepts that were intended for this part. Most items could be answered using slide bars in-between two extremes, e.g. learning alone or in a group as extremes for the question which of these students prefer when learning.

In [Fie17], Field describes independent variables (or predictor variables) as those that are manipulated by an experimenter, in this case whether or not students get to use the Learning Units. A dependent variable (or outcome variable) is the variable that is thought to be affected by this manipulation. The process of trying to measure these variables is called operationalizing.

The two main dependent variables in this research approach are motivation and competencies.

Auf dieser Seite siehst du einige Fragen zu deinem Wissen rund um die Veranstaltung 'Reaktive Systeme'. Du bekommst die Aufgaben auf dieser Seite später erneut und wirst dann gebeten sie zu beantworten.
Lies dir nun erstmal die folgenden vier Aufgaben in Ruhe durch und überlege dir, wie du sie lösen würdest.

Gegeben sei eine monotone Funktion $f : D \to D$ und ein vollständiger Verband $(D, \sqsubseteq)$ mit $D \triangleq 2^A$ für eine endliche Menge A.

Was ist der größte Fixpunkt von f für ein passendes m aus den natürlichen Zahlen?

Figure 5.3: An example of the questions before the QCM questionnaire in survey 1.

	Trifft nicht zu						Trifft zu
Ich mag solche Rätsel und Knobeleien.	○	○	○	○	○	○	○
Ich glaube, der Schwierigkeit dieser Aufgaben gewachsen zu sein.	○	○	○	○	○	○	○
Wahrscheinlich werde ich die Aufgaben nicht schaffen.	○	○	○	○	○	○	○

Figure 5.4: An example of the items of the QCM questionnaire.

To operationalize motivation, the QCM questionnaire was used. This questionnaire is presented in [RVB01], along with its origin, results of studies on it, and indications for its validity. The basic idea of this questionnaire is measuring the current motivation, e.g. to recognize effects of a teaching approach or experiment on learning. The questionnaire is generally used in the following way: Students are presented with instructions on exercises or a test they have to work on. They are then asked to fill out the QCM and work on said exercises or test afterwards. In all three surveys, students were first presented with four questions on competencies (see Figure 5.3 for an example) that spanned the whole content of the two Learning Units for the respective course – FLAT or ReSyst – at this point often without presentation of the answering choices. Students were asked to think about how they would solve these exercises and then fill out the QCM and answer the questions afterwards. When filling out the QCM, students have to answer 18 items (see Figure 5.4 for examples), each on a seven-point Likert scale. In [VR06], Vollmeyer and Rheinberg also published an English version of the QCM. One example of these translated items is: “After having read the instruction, the task seems to be very interesting to me” [VR06, p.251]. The 18 items measure motivation on four different scales [RVB01]:

- Interest: Appreciation for the content.
- Probability of success: Assumptions on getting good results.
- Anxiety: The negative stimulus of failing or being able to endure the pressure.
- Challenge: How much the task is seen as one where good performance is necessary.

For the analysis of the results for each participant, the items are separated on each of the four scales and divided by the number of respective items for this scale.

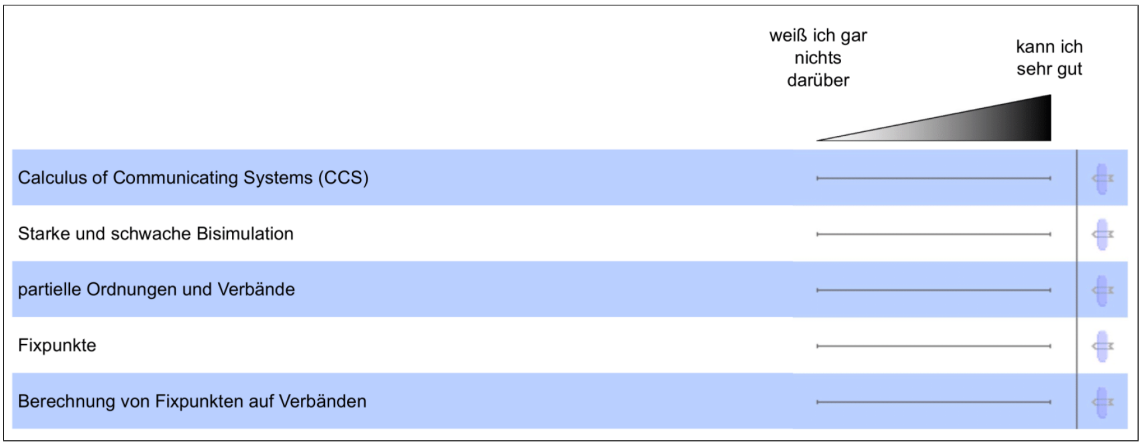


Figure 5.5: Self-assessment for ReSyst.

On the next page, students were, as mentioned previously, again presented with the questions they had already seen prior to the QCM, as well as with a self-assessment on all main topics included in the Learning Units for this course. The self-assessment ranged from “I don’t know anything about this” to “I am very good at this”, see Figure 5.5 for the self-assessment for all ReSyst studies (and surveys).

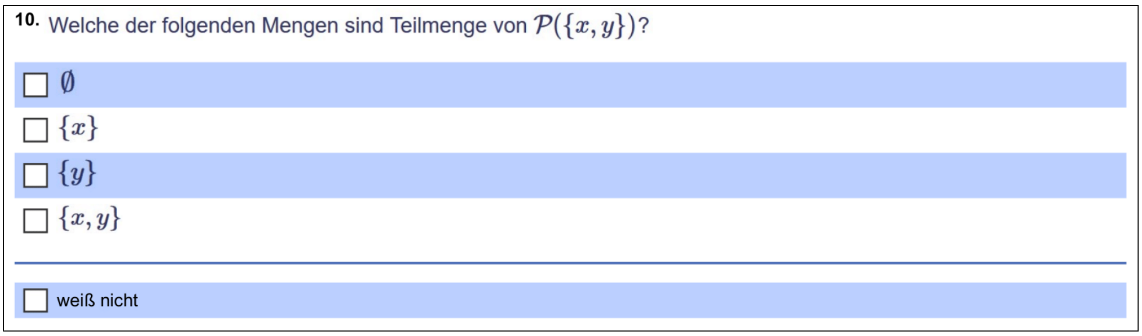
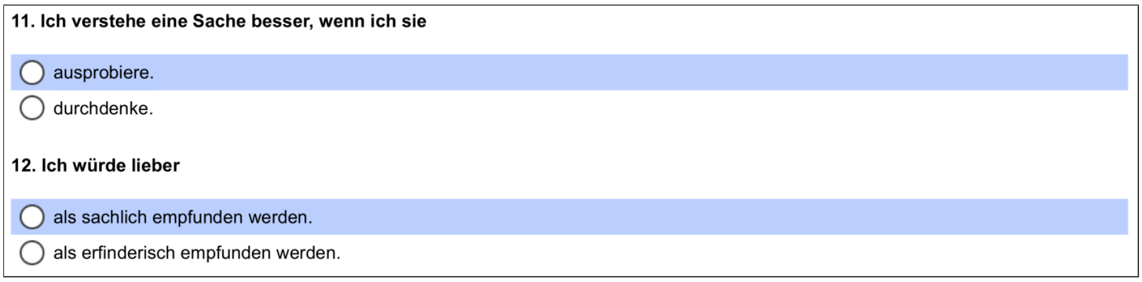


Figure 5.6: Exemplary question on powersets.


11. Ich verstehe eine Sache besser, wenn ich sie

- ausprobiere.
- durchdenke.

12. Ich würde lieber

- als sachlich empfunden werden.
- als erfinderisch empfunden werden.

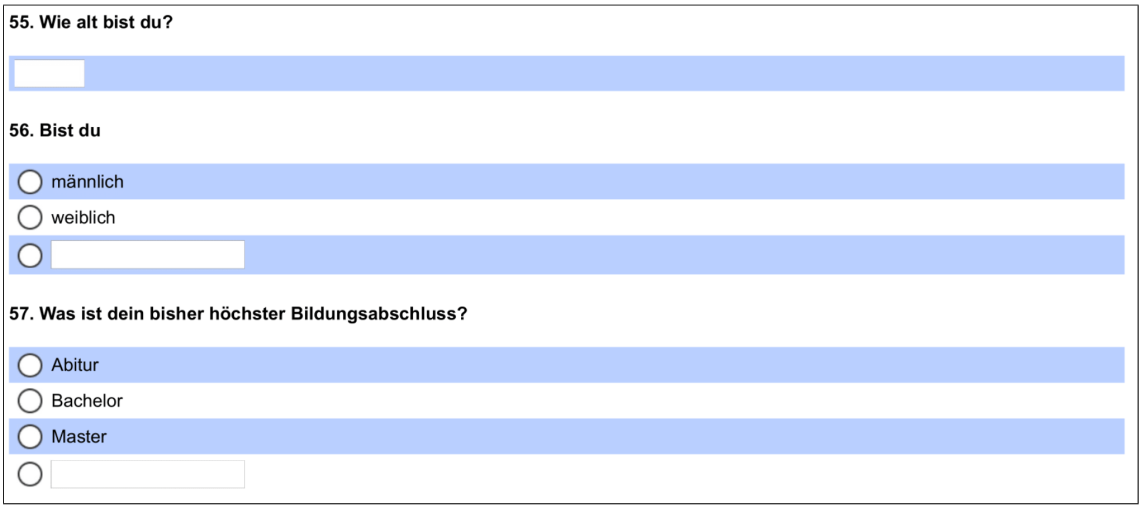
Figure 5.7: Exemplary questions of the ILS questionnaire.

The following questions, the first part of operationalizing competencies, were (both for the FLAT and ReSyst studies) questions on competencies concerning powersets, see Figure 5.6 for an example. In this example, students are asked which of the given sets are a subset of the powerset of $\{x, y\}$. These questions were used for both courses, as these competencies were seen as basic for both areas. The intention of these questions was to measure a base line for the group separation, as well as the analysis of changes in competency levels later.

The "index of learning styles" (ILS) [FS05a] was created by Felder and Soloman and is the corresponding tool to the Felder-Silverman model of learning styles, presented in Section 3.2. The ILS formed the next part of survey 1 to measure students' learning styles. The ILS is originally in English and consists of 44 items with two possible answers each (see Figure 5.7 for two exemplary questions). The original phrasings of these questions are:

- I understand something better after I (try it out / think it through).
- I would rather be considered (realistic / innovative).

The translation used in the studies was based on the one in [Uni11] and was reworked and corrected for the purpose of these studies by a certified translator for English. Analyzing students' learning styles can be done automatically for a single person on the homepage of the ILS, but for research purposes it is done with permission from Richard Felder, who sends the scoring keys on request to researchers. The ILS measures learning styles on the same dimensions as the Felder-Silverman model. The results are computed according to the scoring key, leading to results for each scale on one of the following values: 11a, 10a, 9a, ..., 1a, 1b, ..., 9b, 10b, 11b. On the active/reflective scale, for example, values with "a" represent a tendency to the active dimension, and those with "b" a tendency towards the reflective dimension. The closer these values are towards 11a or 11b, the stronger the preference. For easier comparison and statistical analysis, these values were converted to integers ranging from -11 to 11. The conversion table can be found in Appendix C.



55. Wie alt bist du?

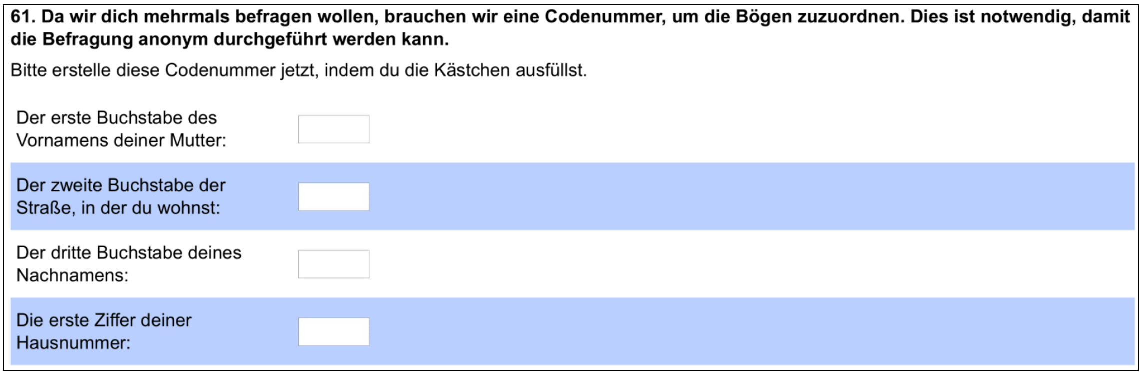
56. Bist du

- männlich
- weiblich

57. Was ist dein bisher höchster Bildungsabschluss?

- Abitur
- Bachelor
- Master

Figure 5.8: Exemplary demographic questions.



61. Da wir dich mehrmals befragen wollen, brauchen wir eine Codenummer, um die Bögen zuzuordnen. Dies ist notwendig, damit die Befragung anonym durchgeführt werden kann.

Bitte erstelle diese Codenummer jetzt, indem du die Kästchen ausfüllst.

Der erste Buchstabe des Vornamens deiner Mutter:

Der zweite Buchstabe der Straße, in der du wohnst:

Der dritte Buchstabe deines Nachnamens:

Die erste Ziffer deiner Hausnummer:

Figure 5.9: Generation of the pseudonyms.

Afterwards, demographic questions were posed for all students (see Figure 5.8 for three exemplary questions). The exemplary questions ask for sex, gender and educational background of the participants. Following these demographic questions, students were asked to generate a pseudonym for themselves, see Figure 5.9. The questions to answer for the pseudonym asked students to enter

- the first letter of their mother's first name,
- the second letter of the street they live in,
- the third letter of their own last name and
- the first digit of their house number.

The last page of the survey thanked students for their participation and referred them with a link to the Moodle system.

5.4.2 Survey 2

The second survey, after group A had had access to the respective first Learning Unit for two weeks, again started – after a brief introduction – with four questions the students were asked to look at and to think about how to solve them. These questions were rather similar to those in the first survey. Afterwards, students were again asked to fill out the QCM, followed by the self-assessment on the topics of the Learning Units in this course and the actual possibility to work on the questions they had already seen before the QCM.

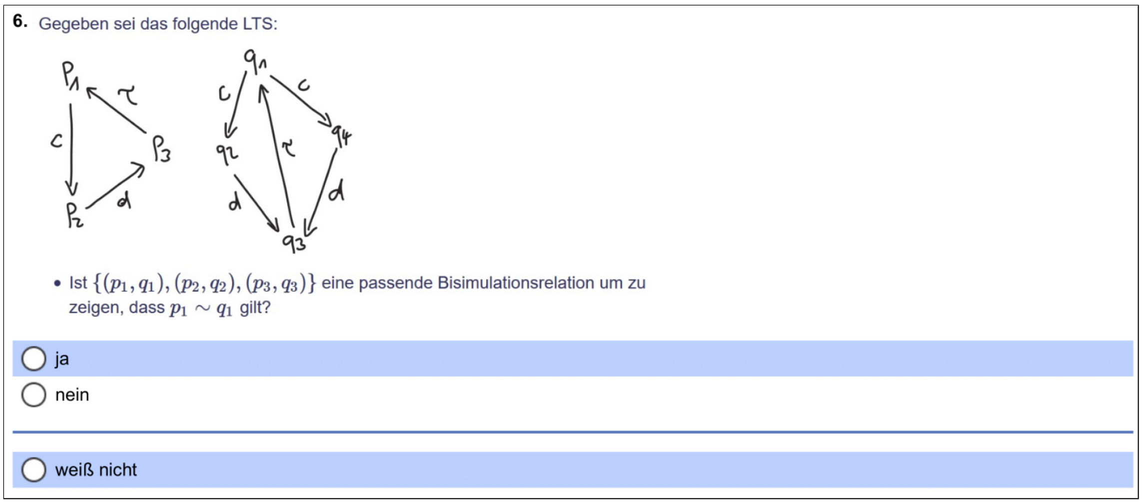


Figure 5.10: Exemplary question on the competencies concerning ReSyst.

These questions were followed by the second part to operationalize the competencies towards the content (see Figure 5.10). Even though these questions were for the most part single-choice questions, answering them correctly required a considerable amount of competency in the area.

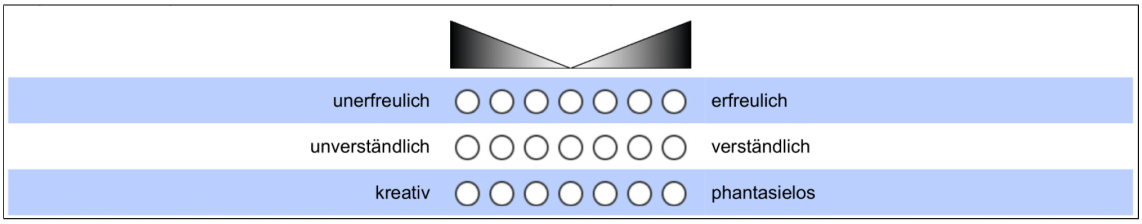


Figure 5.11: Exemplary items of the UEQ.

Afterwards, a branch in the questionnaire followed, where students were asked whether they had had access to the respective first Learning Unit. If students answered that they had not, they were forwarded to the end of the questionnaire, to generate their pseudonym again.

If the students had had access, they were forwarded to the “user experience questionnaire” (UEQ) [LSH06], measuring the UX of the students using 26 item pairs (e.g. annoying/enjoyable) on a seven-point Likert scale ranging from one part of the pair to the other, see Figure 5.11 for exemplary items. The exemplary items in the English version of the questionnaire [LHS08] translate as follows:

- Annoying / enjoyable
- Not understandable / understandable
- Creative / dull

UX is measured by this questionnaire on six scales (explained according to the UEQ handbook that can be found in several languages on the UEQ webpage [Tea]):

- Attractiveness: What is the overall impression of a product?
- Perspicuity: How easy can users learn to use the product?
- Efficiency: Can users solve tasks without feeling unnecessary effort?
- Dependability: Do users feel in control of the interaction?
- Stimulation: Are users excited / motivated to use the product?
- Novelty: Is the product innovative?

The results of the UEQ can be analyzed using the corresponding tool, that can also be found on the UEQ webpage [Tea], testing the results also against a very large benchmark of test results using the UEQ. Due to a technical error one of the item pairs belonging to the novelty scale was not measured in several cases.

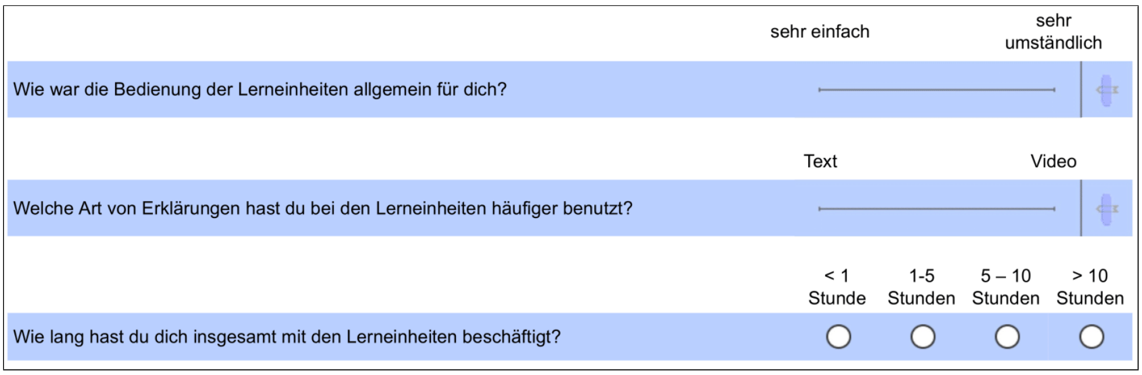


Figure 5.12: Exemplary questions on the usage of the Learning Unit.

In addition to the UEQ, participants were asked five more questions, on how easy using the Learning Unit was for them, whether they preferred explanations as text or video, how many hours they approximately used the Learning Units and two open questions on difficulties they had encountered and ideas for improvements of the Learning Units (see Figure 5.12 for exemplary questions).

Afterwards, students were again asked to fill out the questions generating their pseudonym and thanked for their participation.

5.4.3 Survey 3

Survey 3 was structured exactly as survey 2, with the only differences being that the questions before the QCM were again slightly different. The later questions on competencies now concerned the content of the second Learning Unit, and before the branch in the questionnaire, students were now asked whether they had had access to the respective second Learning Unit.

5.4.4 Follow-Up Survey

The follow-up surveys took place after the respective examination of the course was finished and graded, and were only used in the *FLAT Berlin* and *ReSyst Berlin* courses. Students were first asked to answer the UEQ and the further questions on usage of the Learning Units, then they were asked for their grade ranges. Finally, they were again asked to generate their pseudonym and thanked for their participation.

5.5 Target Group

In this section, insight will be given into the actual group of participants, based on the first surveys in all six study locations. It is important to note that not every single item will be discussed here, but only those considered to be of particular interest. An overview of the participation can be found in Table 5.1. It sums up to a total of 377 surveys filled out by regular participants, and 45 surveys filled out by repeaters. Table 5.2 gives an overview how many students in the three main locations answered all three surveys.

Students were asked for their sex as part of the demographic questions. The results can be found in Table 5.3. In all cases (except for the six repeaters in the *FLAT Duisburg-Essen* study), the majority of participants are male students, but it is interesting to note that in all of the larger studies, a considerable amount of female students also participated. The given alternative option, where students could enter an open answer, was seldom used.

Table 5.1: Participation overview for all six study locations. The additional number of repeaters is displayed in brackets.

Location	Survey	Group A	Group B
FLAT Berlin	1	37 (4)	37 (4)
	2	21 (3)	24
	3	15 (3)	21
FLAT Duisburg-Essen	1	11 (3)	12 (3)
	2	4	2 (2)
	3	2	2 (1)
FLAT Potsdam	1	12 (7)	16 (3)
	2	4 (5)	10 (1)
	3	4 (3)	5
ReSyst Aachen	1	2	2
	2	1	1
	3	2	1
ReSyst Berlin	1	27 (1)	26 (2)
	2	13	16
	3	11	15
ReSyst Salzburg	1	5	4
	2	5	2
	3	3	2

Table 5.2: Participation overview for *FLAT Berlin*, *FLAT Potsdam* and *ReSyst Berlin*, all reduced to participants that filled out all three surveys.

Location	Group A	Group B
FLAT Berlin	15	18
FLAT Potsdam	4	3
ReSyst Berlin	9	12

Table 5.3: Answers of study participants on their sex.

	Male	Female	(Open Answer)
FLAT Berlin	54	19	1
FLAT Duisburg-Essen	18	5	0
FLAT Potsdam	16	11	0
ReSyst Aachen	3	0	1
ReSyst Berlin	34	18	1
ReSyst Salzburg	7	1	1
FLAT Berlin repeaters	7	1	0
FLAT Duisburg-Essen repeaters	3	3	0
FLAT Potsdam repeaters	6	3	1
ReSyst Berlin repeaters	1	2	0

Unsurprisingly, the means of students' ages were quite close, and almost identical for the FLAT courses. The results can be found in Table 5.4. None of the studies was unusual, where the age group is considered.

Table 5.4: Mean age of participants.

FLAT Berlin	22.56
FLAT Duisburg-Essen	22.13
FLAT Potsdam	22.96
ReSyst Aachen	23.25
ReSyst Berlin	22.74
ReSyst Salzburg	24.56
FLAT Berlin repeaters	24.13
FLAT Duisburg-Essen repeaters	22.67
FLAT Potsdam repeaters	22.50
ReSyst Berlin repeaters	23.00

Table 5.5: Highest degrees of participants.

	Abitur	Bachelor	Master	(Open Answer)
FLAT Berlin	54	11	2	7
FLAT Duisburg-Essen	19	4	0	0
FLAT Potsdam	24	4	0	0
ReSyst Aachen	0	4	0	0
ReSyst Berlin	48	4	1	0
ReSyst Salzburg	2	3	2	2
FLAT Berlin repeaters	5	2	1	0
FLAT Duisburg-Essen repeaters	6	0	0	0
FLAT Potsdam repeaters	10	0	0	0
ReSyst Berlin repeaters	2	0	1	0

For a better overview of the students participating, they were also asked for their highest degree. The results can be found in Table 5.5. By far the most students stated Abitur (corresponding to high school graduation), but a considerable amount of students that already own a bachelor degree can also be found. This is not surprising for the courses in Aachen and Salzburg, as these were master courses.

To summarize further results that are not included as separate tables: In all studies, 184 students stated to currently be in a computer science bachelor degree program, 6 in a computer science master degree program and 28 in a variety of other degree programs, including Wirtschaftsinformatik (often translated to business informatics), a math degree program and even two PhD programs. In the surveys, students were also asked, whether they had had computer science in school. 68 students had no computer science in school, 38 in-between eighth and tenth grade and 103 above tenth grade. Of these 103, 63 had participated in computer science as a regular course and 40 in an intensive course.

As the Learning Units were created under the assumption that students basically knew how to use a learning management system already, they were also asked how they felt about the usage of such systems, with several named examples (ISIS – the system used at Technische Universität Berlin, L^2P – the system used at RWTH Aachen University at the time, Moodle and Blackboard). Students could choose an answer concerning the statement that they felt comfortable with the usage on a slide bar from 1 (agree) to 101 (disagree). The results can be found in Table 5.6 and are as expected.

Table 5.6: Mean and standard deviation (in brackets) on how familiar students feel working with learning management systems. Possible values are between 1 and 101. Values close to 1 are positive.

	Used to LMS
FLAT Berlin	16.56 (23.32)
FLAT Duisburg-Essen	22.57 (17.52)
FLAT Potsdam	15.19 (17.74)
ReSyst Aachen	1.00 (0.00)
ReSyst Berlin	19.92 (27.12)
ReSyst Salzburg	20.11 (23.80)
FLAT Berlin repeaters	17.25 (24.53)
FLAT Duisburg-Essen repeaters	23.83 (18.04)
FLAT Potsdam repeaters	19.20 (23.33)
ReSyst Berlin repeaters	1.00 (0.00)

Table 5.7: Mean student results on self-regulated learning (standard deviation in brackets) with values in-between 1 and 101. Values close to 101 indicate strong self-regulation.

	Self-Regulated Learning
FLAT Berlin	63.63 (14.29)
FLAT Duisburg-Essen	63.86 (10.92)
FLAT Potsdam	65.45 (10.65)
ReSyst Aachen	64.75 (9.43)
ReSyst Berlin	66.07 (12.65)
ReSyst Salzburg	62.56 (18.27)
FLAT Berlin repeaters	57.31 (16.66)
FLAT Duisburg-Essen repeaters	55.30 (8.37)
FLAT Potsdam repeaters	57.70 (17.02)
ReSyst Berlin repeaters	71.53 (7.96)

Again on a scale from 1 to 101, but with large values being a good result, students were also asked, using several items, on their abilities concerning self-regulated learning (Table 5.7) and their computer affinity (Table 5.8). These parts of the questionnaire were self-constructed, as explained in Section 5.4. Therefore, there are no existing results for comparison. However, the results seem to indicate that the students are to a certain extent good self-regulated learners. This is useful for the concerned approach. Students also overall have high computer affinity, which is not surprising for computer science students. It can be assumed that the results on self-regulated learning would be lower for the whole course. Those students that participated in the study are presumably those who are better performers, more motivated and better in self-organization.

Table 5.8: Mean student results on computer affinity (standard deviation in brackets) with values in-between 1 and 101. Values close to 101 indicate good computer affinity.

	Computer Affinity
FLAT Berlin	71.71 (14.69)
FLAT Duisburg-Essen	67.93 (15.86)
FLAT Potsdam	68.25 (16.44)
ReSyst Aachen	78.06 (12.02)
ReSyst Berlin	70.04 (14.29)
ReSyst Salzburg	71.11 (14.94)
FLAT Berlin repeaters	57.31 (16.66)
FLAT Duisburg-Essen repeaters	59.50 (20.41)
FLAT Potsdam repeaters	67.43 (21.36)
ReSyst Berlin repeaters	84.33 (6.79)

Table 5.9: Mean and standard deviation (in brackets) for learning styles of course participants (part 1).

	Active / Reflective	Sensing / Intuitive
FLAT Berlin	0.99 (3.57)	-1.68 (5.26)
FLAT Duisburg-Essen	-0.22 (3.55)	-3.52 (4.76)
FLAT Potsdam	0.46 (4.69)	-0.32 (4.84)
ReSyst Aachen	1.50 (5.00)	-4.00 (4.16)
ReSyst Berlin	-0.13 (4.32)	-1.34 (4.96)
ReSyst Salzburg	0.56 (1.76)	0.11 (4.81)
FLAT Berlin repeaters	-0.75 (5.06)	-1.75 (5.01)
FLAT Duisburg-Essen repeaters	0.33 (3.72)	-5.33 (2.94)
FLAT Potsdam repeaters	0.40 (4.43)	-3.60 (2.50)
ReSyst Berlin repeaters	-2.33 (3.06)	-1.67 (2.31)

Table 5.9 and Table 5.10 present the results of the ILS, concerning the students' learning styles. For the active/reflective dimension, the results are very balanced. For the sensing/intuitive dimension, there seems to be a tendency towards sensing learners. Interestingly, as discussed in Section 3.2, Felder and Silverman stated that the majority of engineering students are also sensing learners. The visual/verbal dimension presents strong tendencies towards visual learners, which indicates a need for pictures and clear visualizations in the learning material. For the sequential/global dimension, there seems to be no clear tendency. Both might be present to a different extent.

Many of the variables discussed here for the target group will later be correlated with each other, to find out more about what influences the usage of the Learning Units. The results can be found in Section 6.4.

Table 5.10: Mean and standard deviation (in brackets) for learning styles of course participants (part 2).

	Visual / Verbal	Sequential / Global
FLAT Berlin	-5.72 (3.92)	-0.31 (4.44)
FLAT Duisburg-Essen	-5.87 (3.46)	-1.87 (3.18)
FLAT Potsdam	-5.71 (3.83)	0.07 (4.16)
ReSyst Aachen	-5.50 (4.12)	2.00 (2.58)
ReSyst Berlin	-4.92 (3.66)	-1.15 (4.62)
ReSyst Salzburg	-4.87 (4.41)	-1.44 (3.97)
FLAT Berlin repeaters	-5.75 (3.69)	2.14 (2.14)
FLAT Duisburg-Essen repeaters	-5.67 (3.27)	-4.67 (3.88)
FLAT Potsdam repeaters	-5.20 (4.57)	1.40 (4.09)
ReSyst Berlin repeaters	-6.33 (3.05)	1.67 (2.31)

5.6 Discussion of Low Participation

Overall, only a small percentage of students per course participated in the studies and even fewer fully participated by filling out all three respective surveys. The following section will discuss this problem briefly. In [NRA+02], Naps et al. state that it is generally hard to get students to use educational tools. As only few students participated per course in the studies, those are presumably not representative concerning their level of performance and motivation. Where the level of performance is concerned, this is further investigated in the follow-up surveys. The results of these can be found in Section 6.5.2. 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 analyzed using the *qualitative content analysis* according to Mayring [May00]. The interview guidelines of these interviews can be found in Appendix D.1, examples of the corresponding analysis can be found in Appendix D.2.

The problem of low participation was doubtless increased by the choice of the ReSyst topics, which is a smaller course in Berlin than all the FLAT courses and even smaller in the other locations, as these were computer science master courses. As the author assumed a higher percentage of participation beforehand, this was not assumed to be problematic.

In combination with the low percentages of participation, however, it resulted in data for the studies in Aachen, Duisburg-Essen and Salzburg that contained too few participants to conduct an appropriate statistical analysis. Therefore, the following analysis was limited to the *FLAT Berlin*, *FLAT Potsdam* and *ReSyst Berlin* studies – those with the largest participation. The results of the other studies can be found in Appendix B.2. As the settings of the studies were very similar, the results for *FLAT Berlin* and *FLAT Potsdam* were analyzed jointly. Another possible problem might have been the idea to integrate the Learning Units as a supplement, which might not have made their usefulness fully clear to all students, especially to those with problems in self-organization.

Chapter 6

Results and Reflection

In the past chapters, the theoretical foundations of the Learning Units were presented, followed by a discussion of the decisions concerning didactics, content and implementation of these units. Afterwards, the general structure of the study and the conditions in the different study locations were presented. Following these presentations of the two main contributions of this dissertation, the creation of the Learning Units and the associated evaluation instrument, the results of the first evaluations will now be stated and discussed. This chapter initially presents an overview how the survey data was pre-processed from the raw data stage to the analysis, and of the statistical tests and analyses used in the process. Then the data and the results of the null hypothesis significance tests are presented and discussed, followed by the findings on UX and correlation between variables. The results of the interviews with several students are being discussed. Furthermore, results of follow-up surveys in two of the survey locations will be discussed. Additional insight is given by the usage of Moodle statistics.

The statistical explanations in this chapter will, if not explicitly stated otherwise, follow the statistics textbook by Andy Field [Fie17].

6.1 Preprocessing and Methodology

The data of those students that had stated to be repeaters in the respective course were separated. They are seen as a slightly different population than those taking part in a course for the first time. Results on this data can be found in the Appendix B. In several cases, students had completely filled out surveys twice. In all these cases, the first set of answers was used for the analysis, as the situation filling out the questionnaire should be as comparable as possible in-between students. If students had already answered the exact same questions, especially their answers on the content questions are expected to differ. Students were identified using pseudonyms. If there was no match for the pseudonym in the Moodle course, the data was not analyzed. If a pseudonym was very close to an existing one (e.g. a student used the pseudonym Arh2 in the second survey instead of Arc2 in the first survey) and this mapping was unambiguous, a typo was assumed, and the pseudonym was corrected.

As a first step in preprocessing the data, the survey data was summarized. In the process, answers on a number of single items are combined to form each participant's score on a specific questionnaire scale. For existing questionnaires, this was done according to the creators' instructions; for self-created scales, mean values or percentages were mostly used to represent the scales. Questions on content were always summarized as percentages to facilitate direct comparisons.

As the outcomes on the scales of the ILS questionnaire (e.g. scores like 11a, 3b, etc.) are impractical for statistical analysis like the computation of correlation coefficients, those values were converted to integers according to Table C.1 in the Appendix. "11a" was, for example, converted to "-11". Data for the UEQ can be additionally analyzed using the official UEQ-tool [Tea], which tests for inconsistencies in the answers. Based on this analysis, two sets of answers of the UEQ were not evaluated due to a very high number of inconsistencies.

In the surveys, the students were asked if they had recently had access to the Learning Unit with the corresponding topic in order to choose whom to show the questions on UX and usage. If a student was part of group B, but answered in the survey corresponding to the first Learning Unit that he or she had accessed it (which would not have been possible with their regular account), the data was filtered, and this students' set of answers to this survey was not evaluated. The same holds for students of group A answering that they had accessed the second Learning Unit.

In the second survey of the *FLAT Duisburg-Essen* study, an unusual cluster of such cases was found. Five out of the six students in both groups answered this question in disaccord with the actual group distribution. In this case, almost all participants answered this question "wrong", whereas this happened very seldom in the other studies. This allows for the assumption that the students had language problems or were distracted in some other way. Therefore other questions might also have been misunderstood. This was so unusual that it led to the exclusion of the results of the *FLAT Duisburg-Essen* study from the main analysis. In further – carefully chosen – parts of the analysis, e.g. where the correlation with additional variables is concerned, this part of the data is – in contrast to the usual data processing – not filtered to gain further insight into the survey data.

The results of the UEQ were not additionally filtered, as the general assumption is that the students answered truthfully and therefore their opinions on UX can be used, regardless of whether they had additionally accessed the Learning Unit they were not supposed to.

The data was analyzed for outliers. In almost all cases, those data sets were seen as unusual but still possible answers. Therefore they were included in the analysis.

The preprocessed data can be found in the digital appendix (Appendix A-PR813). The six studies based on the Learning Units brought insight into the usage of the Learning Units on many levels. Due to the low participation rates, especially for the studies in Aachen, Salzburg and Duisburg-Essen, the following analysis on motivation and competencies concentrates on the combined results of the largest studies – those of the *FLAT* studies in Berlin and Potsdam and the results of the *ReSyst Berlin* study. For all three studies, only those surveys, where a participant has filled out all three surveys are taken into account. The studies in Potsdam and Berlin have been combined. These courses and their situation were seen as comparable. On the contrary, the scenario for the *ReSyst Berlin* study was seen as too different to combine the results.

For the statistical analysis, the programs IBM SPSS Statistics [1] version 25 and Microsoft Excel [2] were used.

6.1.1 Statistics

This section will give a short overview of the main statistical measurements used in the analysis. The *mean* $\bar{x}$ is the sum of the considered values divided by their number N. The *standard deviation* is a measure of how much spread is in the data, i.e. how strongly the values differ. If all values are equal, the standard deviation is zero. The further the values are apart, the more the standard deviation increases. It is computed by:

$$s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{N - 1}}$$

where $x_i - \bar{x}$ denotes for each value the deviance between the value x_i and the mean value $\bar{x}$. The deviances for all considered values are squared and then summed up, divided by one less than the number of values $(N - 1)$. The value of $N - 1$ is called the *degrees*

[1] https://www.ibm.com/de-de/products/spss-statistics
[2] https://products.office.com/de-de/excel

of freedom in this context. Usually, N is used for the whole number of observations (or values) and n for a certain subgroup. In the case of the formula, both n and N denote the number of values, in the dissertation most often the number of study participants in a certain group. As the mean as a statistical measure is heavily influenced by outliers, i.e. uncommonly large or small values, in appropriate cases, the *median* will be reported in the analysis, which is insensitive to outliers. The median $\tilde{x}$ is calculated by ordering the n values in ascending order. The median is then at position $(n + 1)/2$. If the result is whole-numbered, then the corresponding value will be taken (i.e. if the result is 5, then the fifth element is the median). If the result ends with .5, the median is the mean of the values before and after that (i.e. if the result is 5.5, the median is the mean of the fifth and sixth element).

In many cases in the analysis, it is important to compare two means, e.g. the means for groups A and B for the *interest* scale in survey 1 in a certain study location. A very well-known and widely used test for this is the *t-test*, measuring the likelihood that this difference between the means will have been caused by chance, measured by the significance value p. Relevant values of p will be the so-called *significant* values, with $p < 0.005$, and the so-called *suggestive* values, with $0.05 < p < 0.005$. More details on this can be found in Section 6.1.2.

Certain requirements need to be fulfilled for a t-test to be applicable. These requirements can be summarized to the data being spread normally for each tested group, or, to be specific, the so-called sampling variation of the data being normal. The tests used in the analysis to check for these requirements are tests on *skewness* (frequent scores being clustered at the higher or lower end of the range of values in question), *kurtosis* (many extremely high or low scores) and the *Kolmogorov-Smirnov test* (whether the data are generally normally distributed). If one of these tests indicates non-normality in the data, so-called parametric tests like the t-test are ideally not to be used. In this dissertation, the tests on kurtosis and skewness are deemed to indicate non-normality when their value is above one, and the Kolmogorov-Smirnov test is deemed so whenever the significance value p is lower than 0.05. For such cases, non-parametric tests are recommended. The analysis on normality of the evaluation data for the studies in Berlin and Potsdam is presented and discussed in Appendix B.1. The indications for the data not being spread normally are strong throughout the analysis, and therefore the *Mann-Whitney U test*, which is non-parametric, will be used to compare means. The Mann-Whitney U test works by jointly ranking the values for two compared groups from lowest to highest. If the groups are similar, values from both groups should be spread out similarly over those ranks and summing up the ranks for each group should lead to similar values. The test statistic is then computed by:

$$U = n_A n_B + \frac{n_A(n_A + 1)}{2} - R_A$$

where n_A and n_B denote the sample sizes of the groups A and B, and R_A is the rank sum for group A. Based on this test statistic, SPSS computes a so-called *z-score*, which is a standardized measurement for which probability values (the likelihood of this value appearing by chance) are known. Based on these known probabilities, SPSS computes the significance value p from the z-score.

As the Mann-Whitney U test will be the most important test throughout this chapter, this test will be explained by a short example to emphasize the differences to using means:

Two runner groups X (n = 3) and Y (n = 3) are compared for their running skills on a scale from 0 to 20, with 20 being the best score. The runners from group X score 1, 2 and 3 on the test, the runners in group Y score 1, 1 and 20. If we regularly compare the means for both groups, the mean for group X is 2, and the mean for group Y is 7.3, as the mean is heavily influenced by outliers. If the data are ranked, the results are:

Score	1	1	1	2	3	20
Group	X	Y	Y	X	X	Y
Rank	1(2)	2(2)	3(2)	4	5	6

Scores for both groups are put in order, producing ranks from 1 to 6. As the first three scores are all equal, the median of these ranks is used in the calculations, this median is added here in brackets. Based on these ranks, the mean ranks for both groups are computed with the mean rank for group X being 3.67 and the mean rank for group Y being 3.33, which – at least depending on the analysis – more adequately resembles this data set than the regular group means. The test statistic U can be computed as follows:

$$U = n_X n_Y + \frac{n_X(n_X + 1)}{2} - R_X = 3 * 3 + \frac{3(3 + 1)}{2} - 11 = 4$$

SPSS additionally computes a z-score of -0.232 and a p-value of 1. As the p-value is larger than 0.005, the group means do not differ significantly (or suggestively) in this case.

To measure the correlation, i.e. the relationship between two values, *Kendall's* τ is used. τ is more useful for small samples with similar ranks than the alternative *Spearman's* ρ. For easier interpretation of these values, significance values are stated for each case.

As there are many statistical tests and measurements, there are many possible tests that were not used in the analysis. *Bootstrapped tests*, e.g., were not included in this analysis. A bootstrapped test overcomes the problem of the data not being normally distributed by estimating necessary properties of the data by taking a large number of random samples out of the data. This works well in several cases. However, for this analysis, some of the samples (group sizes) are too small to use bootstrapping. The results would not have been reliable. Therefore, non-parametric tests were used.

The main focus of this analysis is to compare the group means at different points in time using Mann-Whitney U tests. Another possibility of comparison is using *analyses of variance* (ANOVAs), in this case, a repeated-measures ANOVA. Such an ANOVA analyzes the changes in group means to find out if there are significant changes over several points in time (i.e. the different surveys). As the different measurements of competencies are especially hard to compare between different points in time, ANOVAs are only briefly part of this dissertation. ANOVAs were computed for the combination of the studies *FLAT Berlin* and *FLAT Potsdam* and additionally for the *ReSyst Berlin* study. No significant differences between the groups were found. For all scales except *anxiety* and the competencies (both for the *FLAT* studies), no suggestive results ($0.005 < p < 0.05$) were found either. The results of an ANOVA state only whether the group results (in the case considered here) are exceptionally different, but not between which groups exactly. If significant (or suggestive) results are found, the groups need to be compared pairwise post-hoc to find out which scores differ significantly or suggestively. For example, there might be a general deviation between the groups over the three points in time, but not related to their use of the Learning Units. For both aforementioned scales, this was the case. The group results were tested using the Wilcoxon signed-rank test (another non-parametric significance test, but for related samples, e.g. one group tested before and after a treatment) and the differences in between groups could not be related to the Learning Units. The results are part of the digital appendix (Appendix A-AN386), but not included in the analysis in Chapter 6.2. The reason for the use of a non-parametric post-hoc test was that, although ANOVAs are generally rather robust for deviations from the normal distribution, the post-hoc pairwise comparisons of group means are not as robust.

6.1.2 Significance Level and Statistical Power

The significance level is the hurdle in a significance test (such as the t-test or the Mann-Whitney U test) from which key value onward a p-value is seen to show a significant result. A significant result is a difference that is unlikely to originate from coincidence. Choosing a comparatively high significance level leads to many effects being seen as genuine, although they might have happened simply by chance. This phenomenon is called a Type I error. The most commonly used significance level is 0.05. In [BBJ$^+$17], Benjamin and a very large number of his colleagues argue for using the more conservative level of 0.005 to improve the reproducibility of scientific results and general scientific standards. This dissertation follows this argumentation and the corresponding significance level. Values in between the "typical" p-value of 0.05 and 0.005, which would have been significant with the usual criterion, are now called *suggestive*, changing the emphasis without ignoring those values which could still be important to analyze. Often p-values very close to the borders of the aforementioned ranges are still seen as relevant, depending on the context and details of an analysis. A p-value of 0.05 is therefore often seen as a suggestive value, even though $p < 0.05$ does not hold for it.

Doing many tests on the same data, as is done in the following analysis, would usually require to adjust (i.e. lower) the significance level to overcome the problem of finding many significant values by chance. Several possible ways of such adjustments have been proposed, a very well known one is the *Bonferroni-Correction.* As the used significance value of 0.005 is already a rather conservative criterion, the significance level is not further adjusted where several tests are done on the same data.

The ability of statistical tests to find an existing effect is called the statistical power of the test. Small sample sizes like the ones in the studies discussed in this dissertation have the problem that only very large existing effects will be found dependably. Smaller effects might be missed even though they exist. This is called a Type II error. The program G*Power[3] [FELB07] [FEBL09] can be used to calculate the necessary sample size in a given situation. Effect size, i.e. how important an effect is, is measured by *Cohen's d* in this program, with effects greater or equal to 0.5 being seen as large effects. For a large effect of 0.5, the used significance level of 0.005, and the commonly used statistical power of 0.8, a total sample size of 228 would have been necessary, according to G*Power. For the studies in the dissertation, this would mean one study with 228 participants. The actual statistical power of the tests in the analysis is not computed for all the cases. For

[3] `http://www.gpower.hhu.de/`

the largest groups (survey 1 in the *FLAT Berlin* study) with 37 participants in both groups, the statistical power is only 0.22. Therefore, there is a considerable possibility that existing effects in the groups have been missed in the analysis as a result of the low participation.

The repetition of the studies is seen as a countermeasure to this problem, as recurring tendencies in the data can still be interpreted beyond solely considering significance values. Therefore, these comparisons can still be useful to find out more about the influences of the Learning Units.

6.1.3 Effect Sizes

Effect sizes are used to assess the importance of an effect. Sharing the effect size, in addition to the significance values when comparing means allows for meta-analyses to be computed more accurately. Following Field [Fie17], the effect size is measured using the *Pearson correlation coefficient r*. The values of this coefficient range from -1 to 1. The sign is only important for the direction of the effect. The size of the absolute value shows the size of the effect.

The correlation coefficient is computed using the z-score as follows (as proposed by Rosenthal [Ros91], cited from Field [Fie17]):

$$r = \frac{z}{\sqrt{N}}$$

Field [Fie17] cites Cohen [Coh88] [Coh92] with the following reference values for Pearson's correlation coefficient (or, to be more exact, for its absolute values):

- r = 0.10 (small effect)
- r = 0.30 (medium effect)
- r = 0.50 (large effect)

The correlation coefficient as a measure of effect size is more easily comparable than the already mentioned Cohen's d, as values for r range only from -1 to 1 and can, therefore, be seen as standardized. One disadvantage of the correlation coefficient is that it is influenced by the group sizes. It needs to be interpreted for all the analyses.

6.1.4 Qualitative Content Analysis

The qualitative content analysis, according to Mayring [May00], is used to analyze communication in a systematic and rule-based way. It can be seen as a framework that needs to be tailored to the concrete analyzed object or material. The start of each analysis is to specify the units of analysis. The *coding unit* is the smallest analyzable unit of the material. The *context unit* is the largest analyzable unit of the material, and the *evaluation unit* states which parts of the material are analyzed in which order. In the case of the open survey questions and the interviews that were analyzed, the coding unit was one statement of an interviewee or survey participant (e.g. "Menü ist noch ein wenig unübersichtlich."), the context unit was the whole interview of this student or all of the participant's answers to the open questions, and the evaluation unit was one interview after the other.

In a basic preparation step, the interviews were reduced to the relevant parts. All parts drifting too far apart from the questions were not evaluated.

The qualitative content analysis follows a rule-based pattern. In the case of the interview analysis, the statements of the participants were paraphrased, if necessary. They were generalized to the underlying statements afterwards, if possible. Then, statements were reduced. Very similar statements of the same participant were reduced to one, very similar statements of different participants were counted for the analysis. If necessary, the categories were reworked. The interviews were all either conducted in person or, in a few cases, via e-mail, video chat or chat. All interviews were conducted by the author independently of the raffling of the vouchers. The interviews (apart from chats) were recorded as audio files and later transcribed.

After about half of the material is analyzed, Mayring [May00] recommends reevaluating the analysis and the categories to make sure that the analysis correctly reflects the interviews. This step was also taken for the interview material.

Categories in the qualitative content analysis can be created in a deductive way based on theoretical considerations or inductively based on the material. In the case of the interviews, the categories were first extracted from the interview questions that can be found in Appendix D.1. After the analysis of several interviews, the categories were reviewed each time, but only one change was necessary. The original category "motivation of participation" could not hold reasons why the interviewees participated and reasons they thought of why others had not. Therefore another category was created for the latter called "possible non-participation reasons".

For the open questions only a simplified version of this analysis was used, due to the small amount of material where paraphrasing was often unnecessary before the statement could be generalized.

6.2 Survey Results

The following section presents the survey results concerning motivation and competencies of the combined *FLAT Berlin* and *FLAT Potsdam* studies and the *ReSyst Berlin* study. As a result of the low participation, the *ReSyst Aachen* study and the *ReSyst Salzburg* study were excluded from this analysis. As was the *FLAT Duisburg-Essen* study, where the aforementioned problems with the large possibility of misunderstood questions played a role in this decision as well. The survey results for all these studies can be found in Appendix B.2.

6.2.1 Motivation – the QCM Questionnaire

The aim of this section is to answer Research Question 3: "How is the learning motivation of the students in a course on theoretical computer science affected by using such an additional learning unit compared to that of students using solely 'classic' teaching material?"

Table 6.1: Mean and standard deviation (in brackets) of motivation for the *FLAT Berlin* and *FLAT Potsdam* studies reduced to those participants that filled out all three surveys, comparing group A (n = 19) and group B (n = 21).

Survey	Scale	Group A	Group B
1	Interest	4.42 (1.38)	4.01 (1.38)
	Probability of success	3.61 (0.65)	3.46 (0.59)
	Anxiety	3.31 (1.31)	3.00 (1.31)
	Challenge	4.75 (0.99)	5.04 (1.01)
2	Interest	**4.62 (1.32)**	4.33 (1.50)
	Probability of success	**3.64 (0.38)**	3.55 (0.48)
	Anxiety	**2.46 (1.08)**	2.69 (1.64)
	Challenge	**4.56 (1.23)**	4.40 (1.12)
3	Interest	4.55 (1.29)	**3.98 (1.25)**
	Probability of success	3.55 (0.52)	**3.40 (0.38)**
	Anxiety	2.31 (1.10)	**2.75 (1.44)**
	Challenge	4.33 (1.10)	**4.50 (1.40)**

The results of the QCM questionnaire are measured on four scales: *interest*, *probability of success*, *anxiety* and *challenge*. On all four scales, the possible values range from 1 to 7. For the scales *interest* and *probability of success*, higher values are preferable. For the scales *anxiety* and *challenge*, lower values are preferable. Both seems rather intuitive in combination with the scale names. As described in Section 6.1, survey results of students that had already heard the course before (repeaters) were analyzed separately.

This analysis can be found in Appendix B.3. First, the results for each of the four scales will be presented. The interpretation follows afterwards.

Table 6.2: Mean and standard deviation (in brackets) of motivation for the *ReSyst Berlin* study reduced to those participants that filled out all three surveys, comparing group A (n = 9) and group B (n = 12).

Survey	Scale	Group A	Group B
1	Interest	4.22 (1.24)	4.48 (1.18)
	Probability of success	3.86 (0.57)	3.77 (0.72)
	Anxiety	4.09 (0.85)	3.20 (1.44)
	Challenge	4.67 (1.30)	4.35 (0.93)
2	Interest	**4.02 (1.09)**	4.22 (1.05)
	Probability of success	**3.94 (0.41)**	3.77 (0.33)
	Anxiety	**3.84 (1.31)**	2.92 (1.84)
	Challenge	**4.61 (0.74)**	3.96 (1.07)
3	Interest	4.20 (1.51)	**4.32 (0.97)**
	Probability of success	3.67 (0.43)	**3.73 (0.79)**
	Anxiety	3.69 (1.34)	**3.02 (1.98)**
	Challenge	4.78 (0.79)	**4.13 (1.13)**

Below, the results of the combined *FLAT Berlin* and *FLAT Potsdam* studies (simply called the *FLAT* studies in the following section) and the *ReSyst Berlin* study are presented. In both cases, the results were reduced to those participants that had filled out all three surveys – one at the beginning of the study and one after group A used the Learning Unit, one after group B used the Learning Unit.

For the *FLAT* studies, the descriptive statistics of the results on motivation are presented in Table 6.1. For the *ReSyst Berlin* study, the corresponding results can be found in Table 6.2.

(*Interest*) For the *FLAT* studies, group A started with a higher value. The value for A stayed higher than the value for B throughout the three surveys. For both groups, the values first increased and then decreased. There seemed overall to be a negative impact on the groups that had used the Learning Unit recently, but the effect was minimal. For the *ReSyst Berlin* study, group B started with a higher value. Throughout the three surveys, group B stayed higher throughout all three surveys. No influence of the Learning Unit could be observed. A graphical representation of the results can be found in Figure 6.1.

(*Probability of success*) For the *FLAT* studies, group A had a higher value in all three surveys. Almost no change could be seen in the group values. This indicates that there was no influence of using the Learning Unit for the probability of succeeding the students experienced. For the *ReSyst Berlin* study, the groups started with rather balanced values.

The value for the group using the Learning Unit seemed to be slightly better in both cases, which might indicate a positive influence of using the Learning Unit. However, this influence could as well be based on sampling variation. A graphical representation of the results can be found in Figure 6.2.

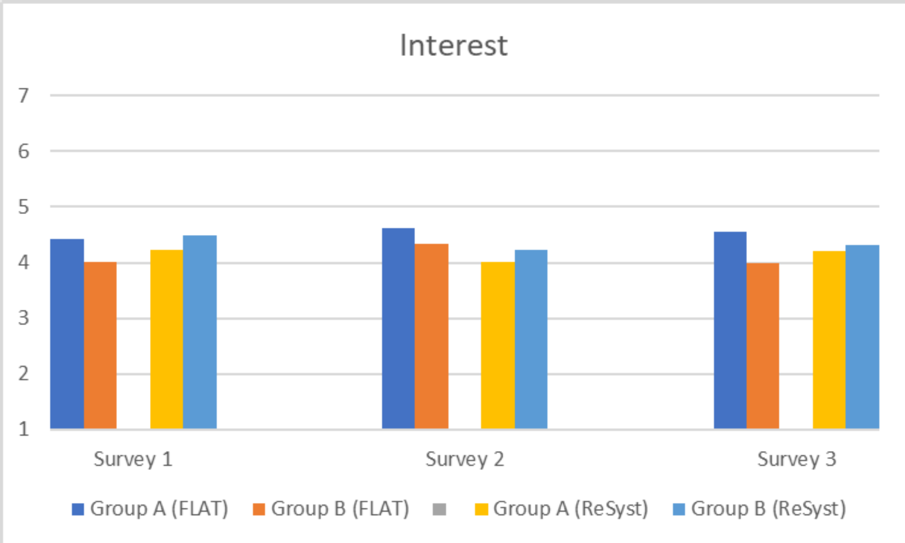


Figure 6.1: Bar graph of *interest* in the combined *FLAT Berlin* and *FLAT Potsdam* studies and the *ReSyst Berlin* study, reduced to participants that filled out all three surveys.

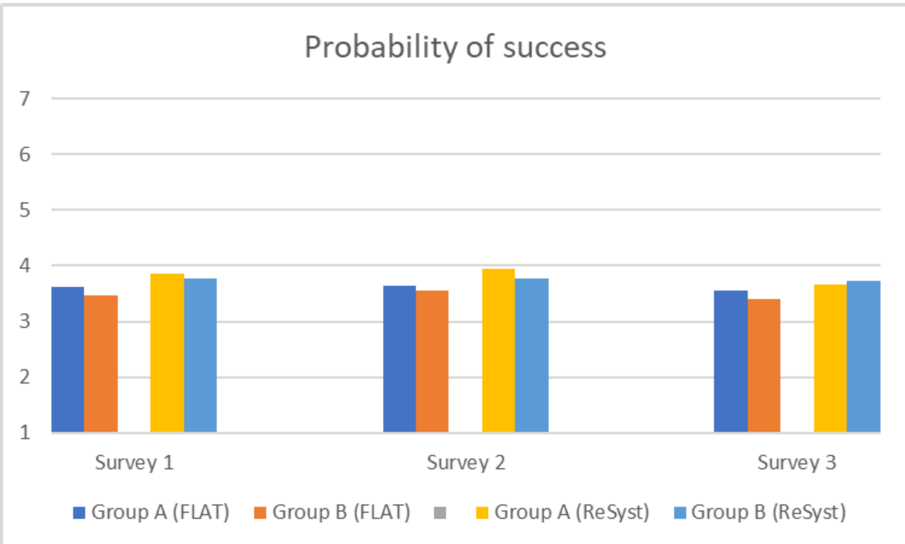


Figure 6.2: Bar graph of *probability of success* in the combined *FLAT Berlin* and *FLAT Potsdam* studies and the *ReSyst Berlin* study, reduced to participants that filled out all three surveys.

(*Anxiety*) For the *FLAT* studies, group A started with a higher value, which decreased over the course of the three surveys. For group B, the value decreased in-between surveys 1 and 2 and then increased slightly in-between surveys 2 and 3. The *anxiety* did not seem to be influenced by using the Learning Unit. The *ReSyst Berlin* study started quite unbalanced on this scale, with a considerably higher level of *anxiety* in group A. This tendency remained the same throughout the three surveys, and there was no indication that using the Learning Unit had influenced the *anxiety* of the participants. A graphical representation of the results can be found in Figure 6.3.

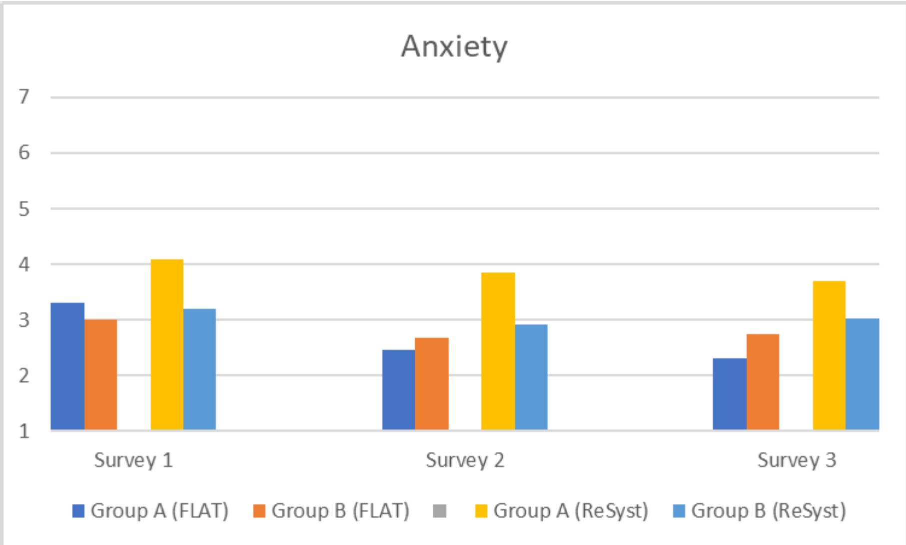


Figure 6.3: Bar graph of *anxiety* in the combined *FLAT Berlin* and *FLAT Potsdam* studies and the *ReSyst Berlin* study, reduced to participants that filled out all three surveys.

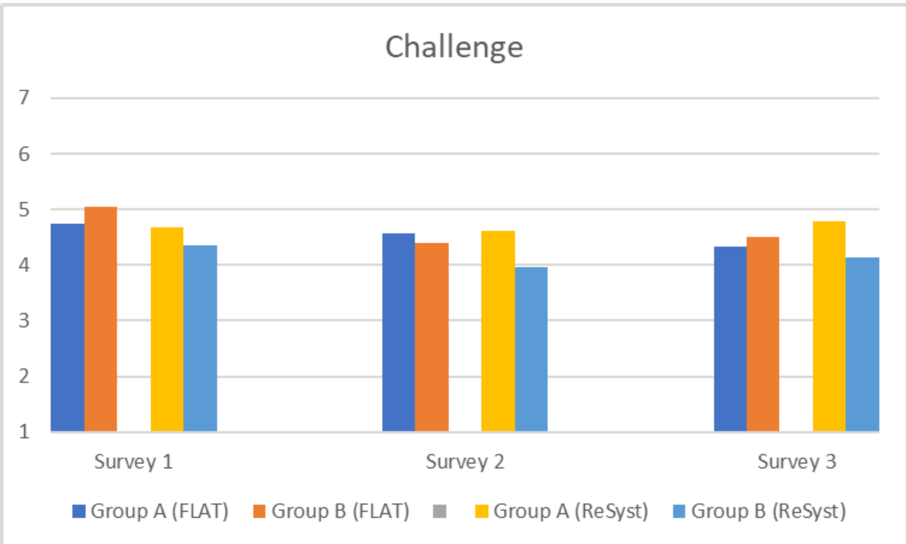


Figure 6.4: Bar graph of *challenge* in the combined *FLAT Berlin* and *FLAT Potsdam* studies and the *ReSyst Berlin* study, reduced to participants that filled out all three surveys.

(*Challenge*) For the *FLAT* studies, group B started with a higher value and then increased less/decreased more for the group that had recently used the Learning Unit. This seems to reflect a tendency that using the Learning Unit increased the *challenge* for the participants. For the *ReSyst Berlin* study, group A started with a higher value, and the value decreased slightly in-between surveys 1 and 2 while the value for group B decreased more strongly. In-between surveys 2 and 3 the values for both groups increased by exactly the same amount. There seemed to be no influence or a weak positive influence by using the Learning Unit. A graphical representation of the results can be found in Figure 6.4.

Table 6.3: Test-statistic U, standardized test-statistic z, significance value p (significant for $p < 0.005$) and effect size r for motivation for the *FLAT Berlin* and *FLAT Potsdam* studies reduced to those participants that filled out all three surveys (N = 40).

Survey	Scale	U	z	p	r
1	Interest	162.50	-1.004	0.320	-0.16
	Prob.o.s.	169.50	-0.824	0.421	-0.13
	Anxiety	167.00	-0.882	0.390	-0.14
	Challenge	243.00	1.183	0.247	0.19
2	Interest	174.50	-0.679	0.503	-0.11
	Prob.o.s.	173.50	-0.721	0.486	-0.11
	Anxiety	202.50	0.081	0.936	0.01
	Challenge	185.00	-0.394	0.708	-0.06
3	Interest	144.50	-1.493	0.138	-0.24
	Prob.o.s.	159.50	-1.105	0.282	-0.17
	Anxiety	229.50	0.816	0.421	0.13
	Challenge	218.50	0.516	0.611	0.08

Table 6.4: Test-statistic U, standardized test-statistic z, significance value p (significant for $p < 0.005$) and effect size r for motivation for the *ReSyst Berlin* study reduced to those participants that filled out all three surveys (N = 21).

Survey	Scale	U	z	p	r
1	Interest	58.50	0.321	0.754	0.07
	Prob.o.s.	50.50	-0.251	0.808	-0.05
	Anxiety	37.00	-1.212	0.247	-0.26
	Challenge	37.50	-1.191	0.247	-0.26
2	Interest	51.00	-0.214	0.862	-0.05
	Prob.o.s.	39.50	-1.054	0.310	-0.23
	Anxiety	39.00	-1.07	0.310	-0.23
	Challenge	34.50	-1.394	0.169	-0.30
3	Interest	47.50	-0.464	0.651	-0.10
	Prob.o.s.	50.00	-0.290	0.808	-0.06
	Anxiety	43.50	-0.75	0.464	-0.16
	Challenge	36.00	-1.288	0.219	-0.28

In Appendix B.1, an overview of the test results concerning skewness, kurtosis and general non-normality for the *FLAT* studies and the *ReSyst Berlin* study are given, concluding that non-parametric tests should be used for significance testing on this data.

For both the *FLAT* studies (Table 6.3) and the *ReSyst Berlin* study (Table 6.4), no suggestive or significant differences could be found when comparing means using the Mann-Whitney U test.

Results Overview

No significant results could be found on motivation and, as stated in Section 6.1.2, the statistical power of the results is low. Therefore it is both possible that tendencies in the survey results can be found where there are no real effects because of sampling variation, or that real effects could not be found. The following will give a short overview of the results on motivation, summarized in Table 6.5, with arrows illustrating if changes in the values corresponded to groups using the Learning Units in the analysis.

Table 6.5: QCM Results Overview ('↗' – positive tendency, '↘' – negative tendency, '–' – no tendency).

	Interest	Probability of success	Anxiety	Challenge
FLAT	↘	–	–	↗
ReSyst Berlin	–	↗	–	–

For the *interest* scale, a minimal negative tendency was found for the *FLAT* studies and no tendency was found for the *ReSyst Berlin* study. The hypothesis for this scale was that the *interest* to learn content was not affected by using such a Learning Unit. This was based on the assumption that *interest* is strongly related to the content, which is not changed by the usage of different instructional material. Interpretations for the negative tendency could be that, contrary to the original hypothesis, the additional engagement with the content lead to the conclusion that the content was not interesting or preferable to the students. Another interpretation can be that the engagement with the content lead to an increased awareness that exercises on this content were too easy or too hard for the students, which both could lead to students losing interest in the topic.

For the *probability of success* scale, no tendency could be found for the *FLAT* studies and a positive tendency for the *ReSyst Berlin* study. The hypothesis for this scale was that the *probability of success* would increase as the learners would be better able to judge the outcome. A possible interpretation of the fact that there was no such tendency found in the *FLAT* studies, in contrast to the original hypothesis, is that the amount of content covered by the Learning Units is not that of the whole course and therefore the *probability of success* was not influenced. A further possible interpretation of the positive tendency found in the *ReSyst Berlin* study is that students had the feeling that their outcome would be improved based on the direct feedback of the Learning Units, or that these Units increased their confidence towards the material in general.

The hypothesis for the *anxiety* scale was that the increased engagement through using the Learning Unit would reduce the feeling of *anxiety* for the students. For both the *FLAT* studies and the *ReSyst Berlin* study, no tendencies could be found, in contrast to the original hypothesis. A possible interpretation is that the anxiety students experience depends more strongly on other factors like their general level of stress or the demands of other courses. As the Learning Units did not cover the whole course, it is possible that their impact was not large enough and therefore did not influence the feeling of *anxiety* of the students.

The analysis for the *challenge* scale found a positive tendency for the *FLAT* studies and no tendency for the *ReSyst Berlin* study. The hypothesis on this scale was, on the contrary, that the *challenge* would be reduced for those using the Learning Unit due to the improved preparation. A possible interpretation for the positive tendency is that the increased amount of engagement with the content led to a more realistic estimation of the difficulties of this content. Therefore this possibly led to a higher perceived *challenge* for the students.

Again, it is important to note that all these tendencies were neither suggestive nor significant. With this overview, Research Question 3 is answered for the scope of this dissertation.

6.2.2 Competencies

The aim of this section is to answer Research Question 4, "How are the acquired competencies of the students in a course on theoretical computer science affected by using such an additional learning unit compared to that of students using solely 'classic' teaching material?" The data evaluated here are not the few questions that were used for the QCM questionnaire, as there was only such a small number of these questions in each survey that covered the topics of both Learning Units of the corresponding course in each case. Only few correct answers could be expected for surveys 1 and 2, as the whole content of these questions or parts of it were still unknown to the students. Due to the smaller number of questions, only an extremely vague assessment of the students' competencies would have been possible. Therefore, the questions used are those concerning preliminary knowledge (power sets) in survey 1, and for surveys 2 and 3 the corresponding topics of the previous Learning Units, e.g. as in Figure 6.5. The analysis for repeaters of the course can be found in Appendix B.3.

Gegeben sei der Verband $(2^{\{a,b,f\}}, \subseteq)$ und eine Funktion $f : 2^{\{a,b,f\}} \to 2^{\{a,b,f\}}$ mit $x \mapsto x \cup \{f\}$.

Wir wollen den größten Fixpunkt berechnen. Was ist das Ergebnis nach der ersten Iteration?

- ○ $\{f\}$
- ○ $\{a, b, f\}$
- ○ $\{a, b\}$
- ○ $\{\}$

- ○ weiß nicht

Figure 6.5: Sample question on fixed points.

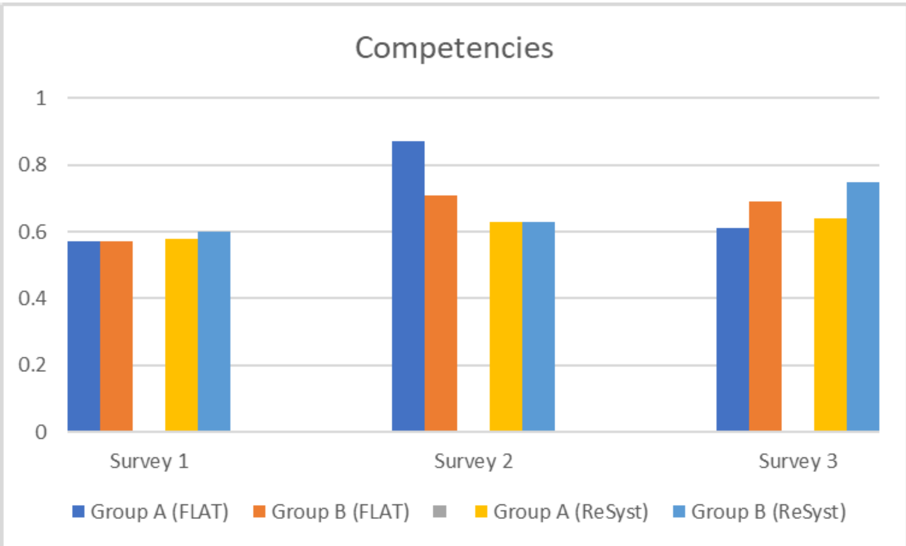


Figure 6.6: Bar graph of competencies in the combined *FLAT Berlin* and *FLAT Potsdam* studies and the *ReSyst Berlin* study, reduced to participants that filled out all three surveys.

In the following, the results for the combined *FLAT Berlin* and *FLAT Potsdam* studies and the *ReSyst Berlin* studies will be discussed. In all those cases, as in the section before, the data were reduced. It solely includes participants that had filled out all three surveys of their study. A graphical representation of the results on competencies for these studies can be found in Figure 6.6, the results can be found alongside the corresponding standard deviations in Table 6.6. The standard deviation (in brackets) is rather high throughout the studies, which shows a high amount of variation in the answers given by the students. The *FLAT* studies started with two well-balanced groups. For both of the following surveys, the score was higher for the group that had previously had the possibility to use the corresponding Learning Units. For the *ReSyst Berlin* study, group A started with a slightly lower value. In survey 2, both groups achieved similar values. Therefore group A had increased more, but only by a very small amount (two percent). In survey 3, group B, which had recently had used the Learning Unit, achieved a considerably higher value (11 percent difference).

In Appendix B.1, the test results concerning skewness, kurtosis and general non-normality for the *FLAT* studies and the *ReSyst Berlin* study are presented, concluding that non-parametric tests should be used for significance testing on this data.

The results of the Mann-Whitney U tests on the results on competencies can be found in Table 6.7. The difference between group A and group B in survey 2 of the *FLAT* studies is suggestive with $p = 0.022$, indicating a strong difference between the values of the groups. As r = -0.38, this constitutes a medium-sized effect. All other test results are neither suggestive nor significant.

Table 6.6: Mean and standard deviation (in brackets) of competencies for the combined *FLAT Berlin* and *FLAT Potsdam* studies and the *ReSyst Berlin* study, reduced to those participants that filled out all three surveys.

Survey	Location	Group A	Group B
1	FLAT Berlin, FLAT Potsdam	**0.57 (0.26)**	0.57 (0.23)
2	group A (n = 19), group B (n = 21)	**0.87 (0.13)**	0.71 (0.21)
3		**0.61 (0.27)**	0.69 (0.23)
1	ReSyst Berlin	0.58 (0.27)	**0.60 (0.31)**
2	group A (n = 9), group B (n = 12)	0.63 (0.26)	**0.63 (0.28)**
3		0.64 (0.17)	**0.75 (0.15)**

Table 6.7: Test-statistic U, standardized test-statistic z, significance value p (significant for $p < 0.005$) and effect size r concerning competencies for the combined *FLAT Berlin* and *FLAT Potsdam* studies and the *ReSyst Berlin* study reduced to those participants that filled out all three surveys.

Survey	Scale	U	z	p	r
1	FLAT Berlin, FLAT Potsdam	184.00	-0.440	0.688	-0.07
2	group A (n = 19), group B (n = 21)	115.00	-2.377	0.022	-0.38
3		237.50	1.067	0.307	0.17
1	ReSyst Berlin	57.00	0.220	0.862	0.05
2	group A (n = 9), group B (n = 12)	53.50	-0.036	0.972	-0.01
3		70.50	1.26	0.247	0.27

Results Overview

Summarizing the insights of this section, it can be concluded that there seemed to be tendencies that the Learning Units improved the students' performance in the content questions. At this point, it is important to again take into account that there are no validated instruments of measuring the acquired competencies in the area of this dissertation. Therefore these results might not cover all parts of the planned competencies, even though the exercises were created with this objective and effort in this direction. Although trends could be identified in the test results in this section, none of the results were significant, but there was a suggestive difference between groups A and B in survey 2 of the *FLAT* studies with r indicating a medium-sized effect. Therefore the difference between the groups seems to be considerable where A had recently used the Learning Unit and also performed better.

The results for the repeaters in the respective studies lead to no definite conclusions, as discussed in Appendix B.4. As discussed in Section 6.1.2, the statistical power of the results is low. Therefore it is both plausible that tendencies in the survey results can be found where there are no real effects because of sampling variation or that real effects could not be found.

With this overview, Research Question 4 was answered for the scope of this dissertation.

6.3 User Experience

This section summarizes the results of the user experience questionnaire (UEQ) and additional results from the survey parts on platform usage to understand how students experienced the Learning Units. Both the UEQ and the other questions on usage were presented in Section 5.4. As the Learning Units were built on the same Moodle system with the same modifications and questions where the only differences are the actual content and questions, the UX for all six studies is discussed at once. The results of the repeaters are not separated here, as no considerable differences between repeaters and non-repeaters are assumed on this aspect. In the following interpretation, all descriptions concerning the meaning of the UEQ scales are based on the official UEQ handbook [Tea].

After the preprocessing steps described in Section 6.1, a total number of N = 96 students answered the user experience questionnaire in all six studies. The results are presented in Table 6.8 and graphically as bar graph in Figure 6.7. The official UEQ handbook [Tea] states that a value below -0.8 is seen as a negative evaluation. A value between -0.8 and 0.8 represents a neutral evaluation, and a value larger than 0.8 represents a positive evaluation. The scales for the Learning Units, therefore, all have a positive evaluation except for *novelty*, which has a neutral outcome.

Table 6.8: Results of the UEQ (N = 96).

Scale	Mean	Std. Dev.	Confidence Interval ($p = 0.05$)
Attractiveness	1.306	0.944	1.117, 1.494
Perspicuity	1.043	0.971	0.849, 1.238
Efficiency	0.802	0.867	0.629, 0.976
Dependability	0.957	0.767	0.803, 1.110
Stimulation	1.124	0.986	0.927, 1.321
Novelty	0.631	0.940	0.443, 0.819

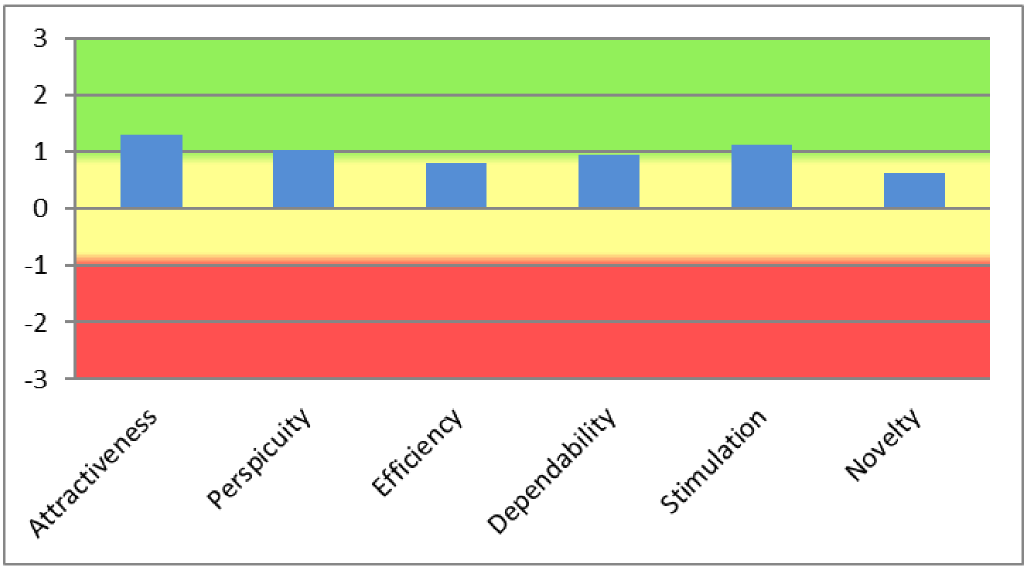


Figure 6.7: Graphic representation of the results (figure created with official UEQ-tool [Tea]).

Considering Table 6.8, the positive evaluation on the scale *attractiveness* shows that the participants liked the Learning Units in general and found them enjoyable or attractive. This indicates that the overall impression for the students was a good one, which is important for them to enjoy using the platform. The positive result on *perspicuity* indicates that it was easy for students to learn how to work with the system. As most students already are familiar with learning management systems and the Learning Units are implemented in Moodle, getting familiar with the Learning Units should not take too much of their time. The evaluation of *efficiency* was still positive but extremely close to the border to a neutral evaluation (0.802 where the border was 0.8). This scale indicates whether users feel able to solve their tasks without additional effort. Possible reasons for this only slightly positive result might have been the issues concerning the overview of the platform and navigation that will reappear several times for the remainder of this chapter. Concerning *dependability*, the positive evaluation can be interpreted as the users feeling in control of using the Learning Units. It was predictable for them what would happen, which is useful for not getting distracted while learning. The positive result on *stimulation* indicates that participants felt that the Learning Units were valuable or even motivating for them. Possible interpretations for the neutral evaluation on *novelty* could have been missing values on this scale due to a technical error as discussed in Section 5.4, but even if the about fifty percent of the data where these values are missing are omitted, the evaluation on *novelty* is still neutral. The approach does not seem to be seen as creative or innovative by the participants that were probably already familiar with some kind of e-learning in general and learning management systems like Moodle in particular. As this approach was intended not to distract the students, not including too much innovation seems to be useful, therefore this result can nevertheless be seen as a good one. Standard deviation is rather high over all scales, indicating a large amount of variation in the data.

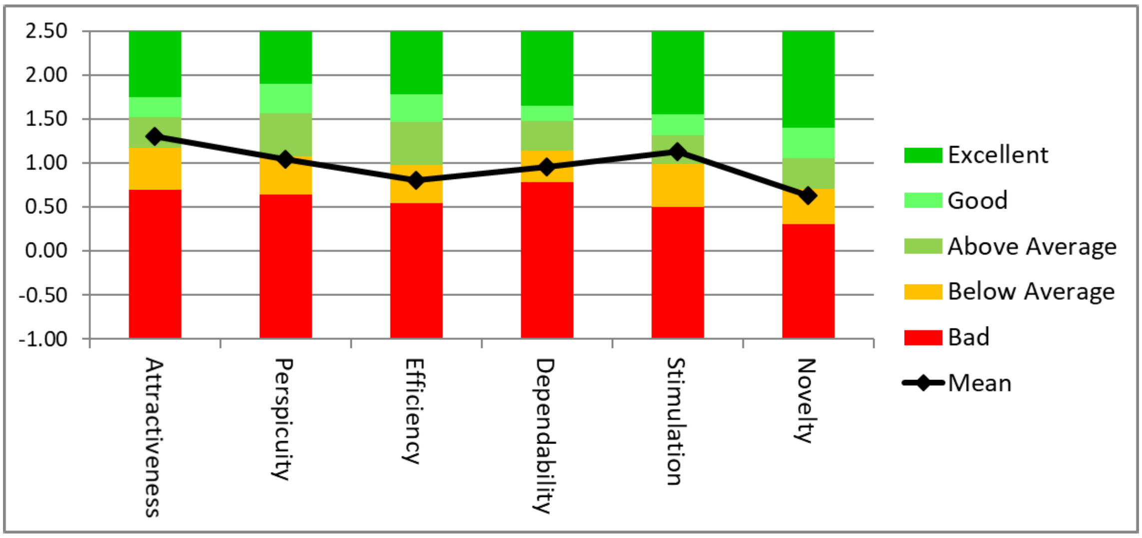


Figure 6.8: Results compared to a benchmark (figure created with official UEQ-tool [Tea]).

Figure 6.8 presents the study results compared to a benchmark based on data from 9905 persons from 246 studies on different products [Tea]. This data was made available by the developers of the UEQ. Here the Learning Units are ranked above average for the scales *attractiveness*, *perspicuity* and *stimulation* and below average for the scales *efficiency*, *dependability* and *novelty*. As very different products are part of this benchmark, it is not surprising the Learning Units are not as *efficient* or *novel* as products or platforms in different areas can be (e.g. video games or online shopping). The mean values below average concerning *dependability* and *efficiency* might originate from the aforementioned navigation problems and those concerning platform overview students had at several points. Improvements for the Learning Units that could be useful on these aspects will be discussed in Chapter 7, as a more *efficient* and *dependable* usage could motivate users to use the Learning Units more intensely.

6.3.1 Usage of the Learning Units

The first additional question asked the students how they felt about usage of the Learning Units on a scale from 1 (very easy) to 101 (very cumbersome). This question was answered by 95 students. The mean value for all six studies was 32.88 with a rather large standard deviation of 24.80. As the standard deviation was so large, the median was additionally computed, which amounted to 29.

A possible interpretation of these results is that the students' overall feeling originates from familiar elements that were used in the Learning Units. Learning management systems are common, and the basic elements text, video and multiple-choice questions are probably familiar to most students. Feedback was always displayed directly after answering a question, making the experience of working with the Learning Units easily controllable. Possibly, getting to know the navigation along the learning paths and the unfamiliar possibility to switch between text and video worsened this overall familiarity with the platform, but as these options were constantly repeated on the different topics, students hopefully learned to use it easily. The good result on this question might be interpreted in such a way.

The students were asked if they used more text or video content in the Learning Unit (as both was available to them) on a scale from 1 (text) to 101 (video). This question was answered by 95 students. The mean value was 45.40, again with a large standard deviation of 38.45 this time. The median value for this scale was 44. The interpretation of this is that usage of text and video was rather balanced, with a tendency to more use of the textual explanations, which could also be a result of textual explanations always being presented first when explanations are accessed. For further versions of the Learning Units, the students should possibly first be able to choose which medium is presented by default.

The third question was how much the students had used the Learning Units in total. The students could choose between 1 (less than one hour), 2 (one hour to five hours), 3 (five hours to ten hours), 4 (more than ten hours). This question was answered by 97 students. The mean value was 1.91, with a standard deviation of 0.54. The median value was 2. It can be concluded that most of the students used the Learning Units between one and five hours in total, which seems a sufficient amount of time, considering they had only access to one of the Learning Units for two weeks during the semester.

6.3.2 Open Questions

For all those students that stated in surveys 2 or 3 that they had had access to the Learning Unit in the past two weeks, additional open questions were posed. These questions focused on which problems occurred with the Learning Units and what should be improved concerning the Learning Units. These answers were analyzed together using qualitative content analysis as described in Section 6.1.4. Answers stating (in all variants) that the students did not see need for improvement or had no difficulties with the Learning Units were filtered out, to get a clearer overview where the Learning Units could be improved. The resulting categories and generalized answers from these open questions can be found in the digital appendix (Appendix A-MA629). As was the case for the UEQ results and the other questions discussed in Section 6.3.1, for the open questions all study results, including repeaters and follow-up surveys, were analyzed at once to get a comprehensive overview of problems and possible improvements on the Learning Units.

Through two refinement steps, five categories and in total, 130 answers were identified. Not all different answers will be discussed here, but only the most important or interesting ones.

The refined categories are:

1. Content
2. Survey
3. Navigation
4. Quizzes
5. General

The first category, *content*, contains answers concerning the content of the units itself. Five answers asked for the speaker in the videos to speak slower, five asked for more complex examples, two for making the text downloadable as a PDF file and three for more material or more covered topics, respectively. Ten answers stated that they had found mistakes in the Learning Unit, which is also not a dramatic amount but shows the need for further improvement on the units themselves. Concerning mistakes, a wrong answer to a content question or a wrong explanation were mentioned. As these mistakes were not pointed out during the usage period of the Learning Unit and mentioned only unspecifically in the answers to the survey, these mistakes might also have been misunderstandings or problems the participant had with the content. As this is an important point, the questions, answers and explanations will be checked for mistakes or ambiguous explanations regularly. Students using the Learning Units have the possibility to use a discussion forum directly on the platform for such issues, or send an e-mail to the author.

The second category, *survey*, contains answers concerning the studies and evaluations, rather than the units themselves. One student asked for the Learning Units to be accessible to everyone, others asked for more reminders for the surveys, more time using the Learning Units, solutions to the survey exercises, or criticized the quality of the surveys. All answers in this category appeared exactly once. Therefore they did not seem to be a huge issue. As there were regular reminders for all surveys, the student asking for more reminders did possibly not regularly check the e-mail address used for registration on the platform. The critique on the quality of the surveys was very unspecific and only appeared once. However, improvements on the surveys are considered for future versions of these surveys, as discussed in Chapter 7.

Category three, *navigation*, contains answers on navigation on the Moodle platform and in the Learning Units. One student asked for an estimate of the required time to be displayed for all Learning Units, which would probably be a useful feature for usage of the Learning Units. 24 students asked for a better overview of the platform and 19 for improvement on the interface. As these are both rather large numbers, navigation and UX should be investigated closer for future versions of the Learning Units to be improved further.

The fourth category, *quizzes*, contains answers specifically concerning the exercises and quizzes in the Learning Units. Six answers asked for more complex exercises, five asked for more detailed solutions and five for more questions in general. These answers indicate that several of the students liked working with these tests and would have preferred more information in the solutions and even a higher level of difficulty.

The fifth and last category, *general*, contains further answers which could not be fit to another category. Among these answers were those concerned with technical problems that were mentioned by students eleven times, which is interpreted as no dramatic amount but indicates room for improvement. Examples of such technical problems are that in some cases the progress bar did not fill up as the students expected, or the progress was not monitored correctly by Moodle if the student was working in several browser tabs. Sometimes the time students needed to answer a set of questions was counted wrong if they closed the session and opened it again. Another answer in this category was that the Learning Unit is not usable without the lectures, which is not problematic, as the Learning Unit is designed to be a supplement.

6.3.3 Results Overview

Overall the UX was assessed as good. The Learning Units were evaluated as attractive and stimulating but not too efficient and novel. As this approach did not include surprising technical innovations but rather intended to be a reliable supplement, the neutral evaluation on *novelty* is not seen as a problem. Making the Learning Units more *efficient* and improving the navigation and general overview for the students is an important issue for future continuations of this approach.

Most students answered that they had used the respective Learning Unit in between one and five hours and overall seemed to be satisfied with using the units. The most important improvements on the Learning Units are a better overview and navigation on the one hand and more content and more complex questions on the other. Ideas to further improve the Learning Units in these directions can be found in Chapter 7.

6.4 Correlation Between Variables

To get further information about how learning and motivation are influenced by other factors, correlation coefficients for the four biggest studies, *FLAT Berlin*, *FLAT Duisburg-Essen*, *FLAT Potsdam* and *ReSyst Berlin*, the largest and therefore most informative groups for this analysis, have been computed and will be analyzed in the following. The corresponding tables containing the correlation coefficients and significance values can be found in the Appendix B.5. The corresponding values for the other studies and repeaters can be found in the digital appendix (Appendix A-CO837). To get a better overview of the large number of coefficients and to minimize the influences of random effects and the possibilities of alpha errors, only effects that were significant ($p < 0.005$) or at least suggestive three times ($0.005 < p < 0.05$) over the course of the three respective surveys in all four studies will be discussed here. It is important to note that neither suggestive nor significant correlation results can be interpreted as a causal relation in one direction or the other. The *FLAT Duisburg-Essen* study is integrated here as the correlation results mostly focus on the respective first surveys for each location and the later content questions. At the time of the first survey, the group of participants was considerably larger than in the later surveys, and there was no indication of participants misunderstanding questions, in contrast to the later surveys of this study.

Variables on

- age,
- sex,
- using computers for learning or entertainment purposes,
- self-regulated learning,
- computer affinity,
- self-assessment on the content of the Learning Units,
- learning alone, in small or large groups and
- learning styles

were all correlated with the QCM scales on motivation and the results concerning competencies. Additionally, the QCM scales were correlated with the results concerning competencies themselves. The results of theses correlations, as far as they are of interest, will be discussed in the following:

The variable *age* was significant ($\tau = 0.470$, $p = 0.003$) when correlated with the *interest* scale in the first *FLAT Duisburg-Essen* survey (Table B.24). This positive relationship indicates a higher interest among higher age groups in the study. With a mean age of 22.13, the *FLAT Duisburg-Essen* is not unusual compared to, e.g. the *FLAT Berlin* study (mean age 22.56) or the *FLAT Potsdam* study (mean age 22.96). As can be seen in Figure 6.9 compared to Figure 6.10, the *interest* for the *FLAT Berlin* study is spread out considerably more. Even though it is not a large sample, the participants at Universität Duisburg-Essen with a higher age seem to have a higher value on the *interest* scale. Possibly, older students at Universität Duisburg-Essen have already heard other courses or studied another subject and made a more conscious decision to hear this course and are therefore more interested. The correlation might as well be influenced by other, unknown factors. Apart from that, no clear tendencies for *age* correlated with other variables were found.

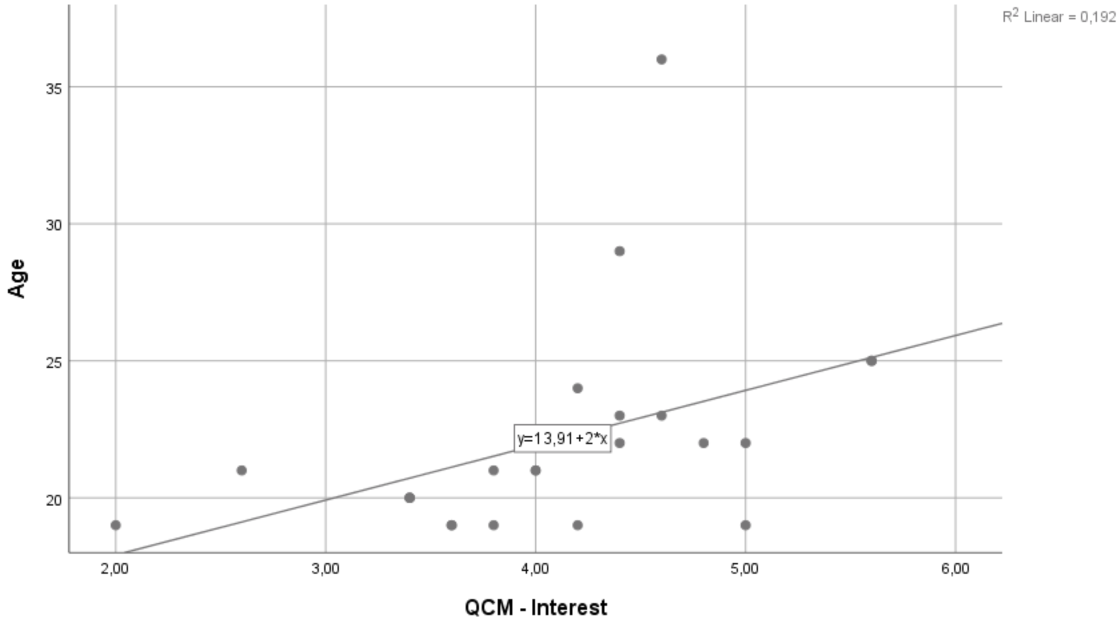


Figure 6.9: Scatterplot for the variables age and the *interest* scale in the first survey of the *FLAT Duisburg-Essen* study.

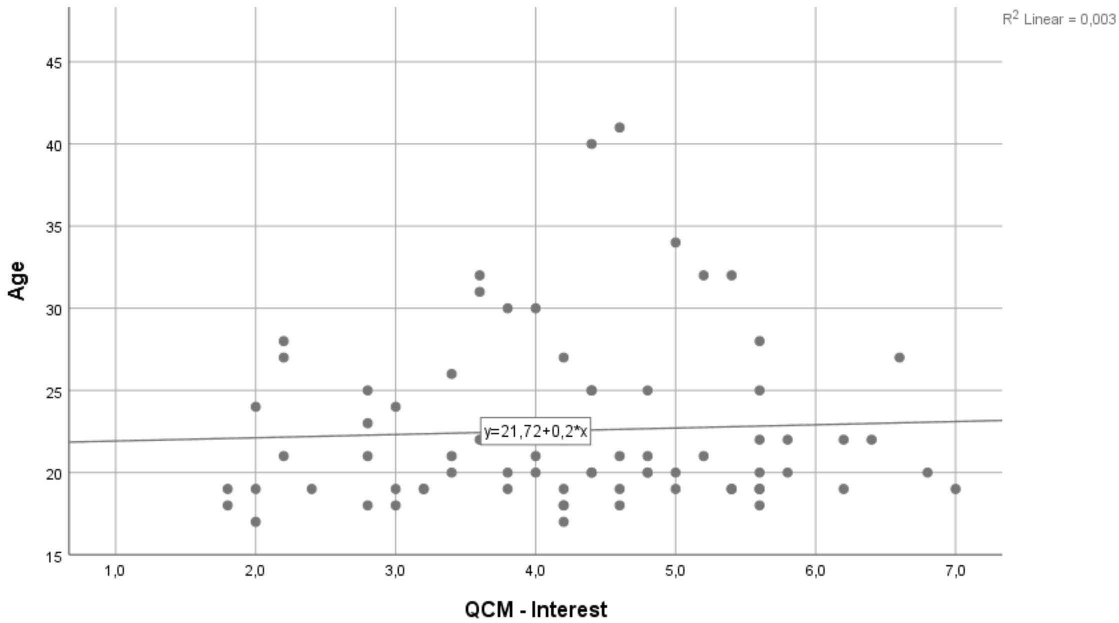


Figure 6.10: Scatterplot for the variables age and the *interest* scale in the first survey of the *FLAT Berlin* study.

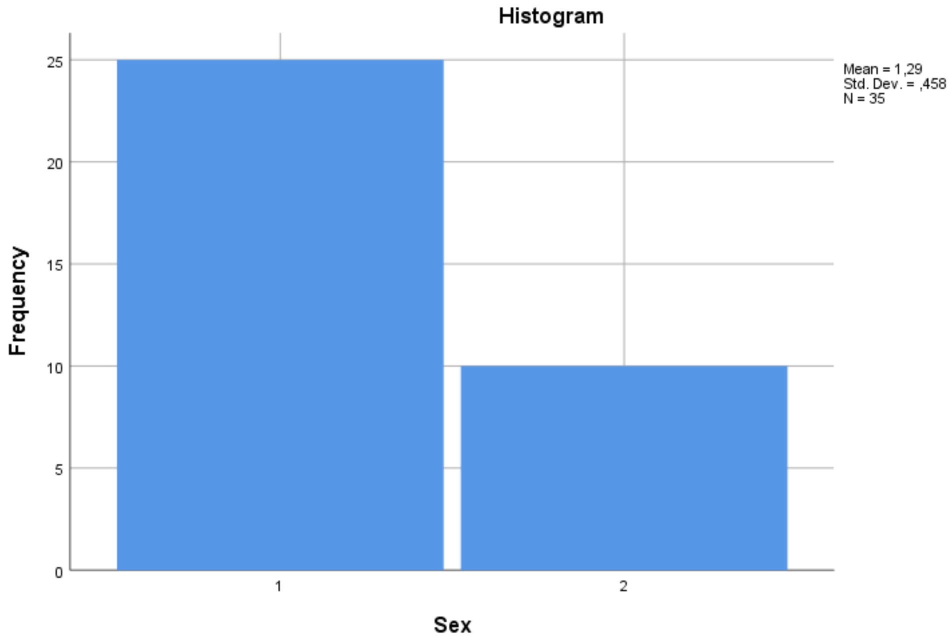


Figure 6.11: Histogram of the variable sex in the third survey of the *FLAT Berlin* study.

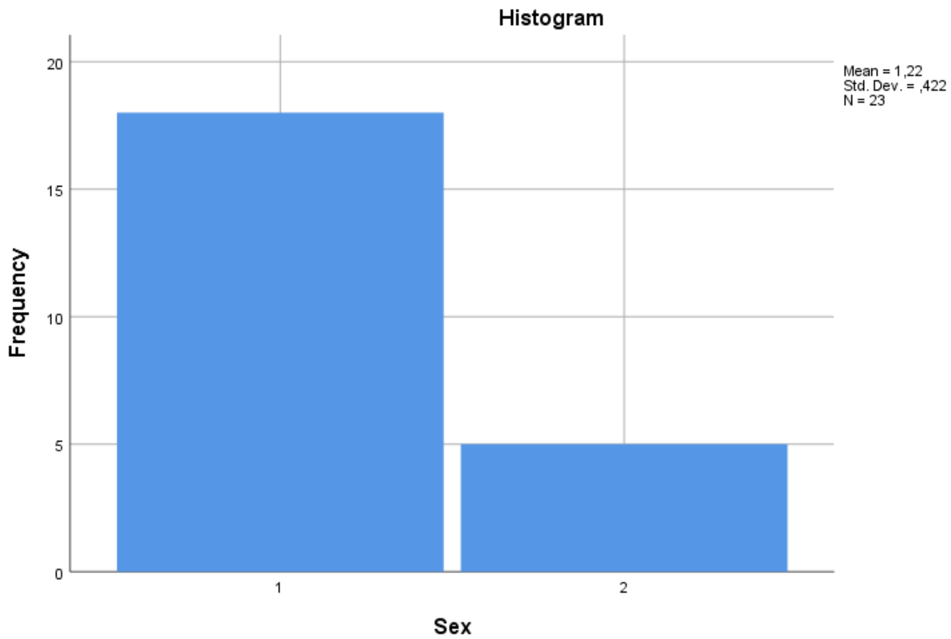


Figure 6.12: Histogram of the variable sex in the first survey of the *FLAT Duisburg-Essen* study.

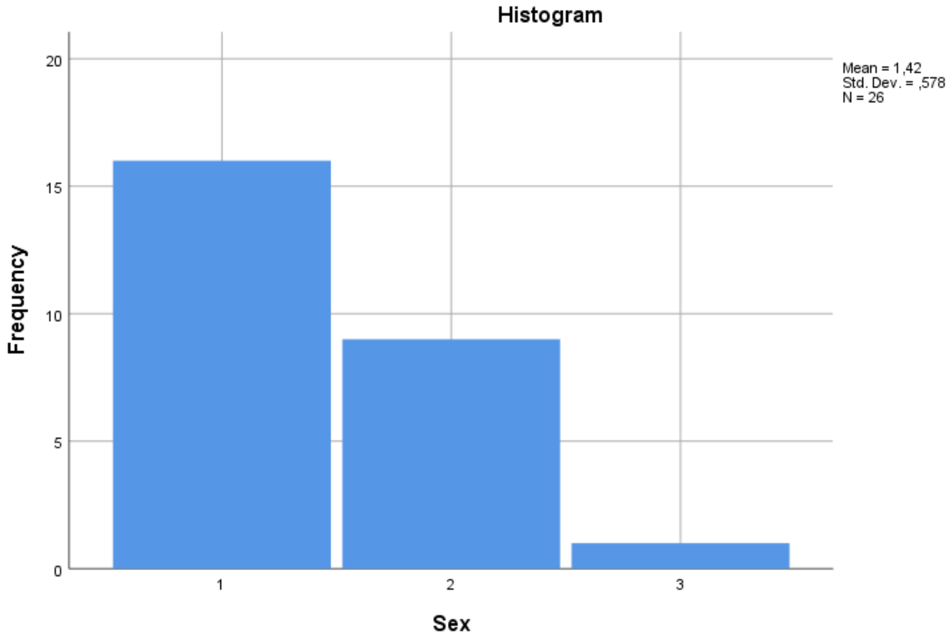


Figure 6.13: Histogram of the variable sex in the third survey of the *ReSyst Berlin* study.

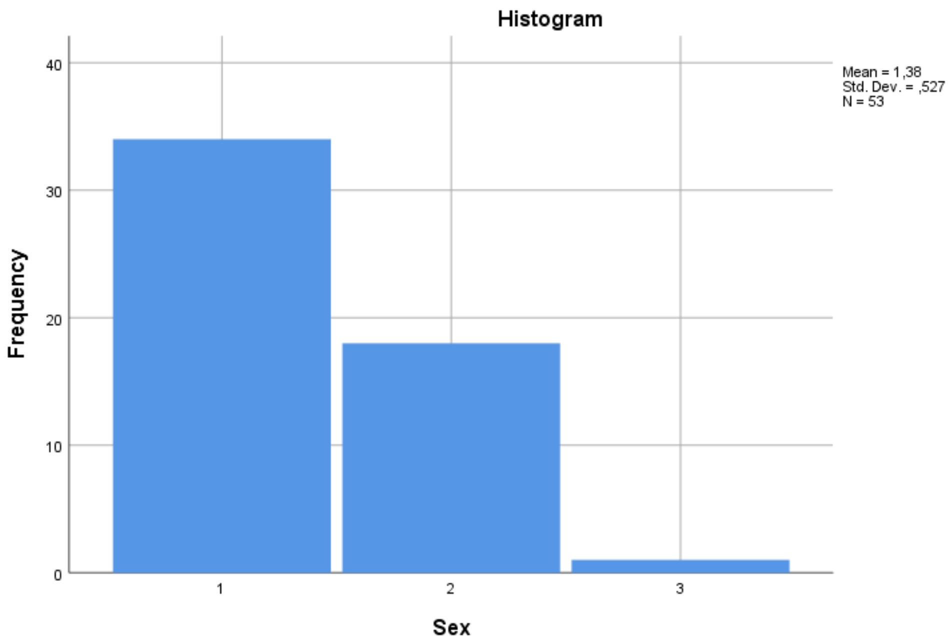


Figure 6.14: Histogram of the variable sex in the first survey of the *ReSyst Berlin* study.

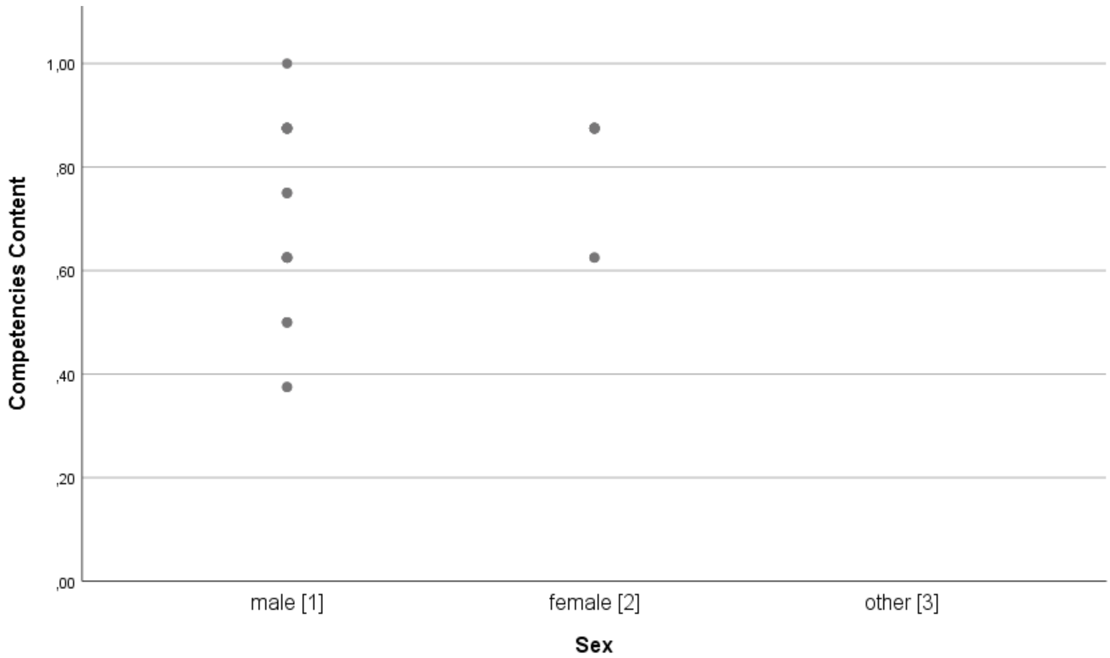


Figure 6.15: Scatterplot for the variables sex and competencies in the third survey of the *FLAT Berlin* study.

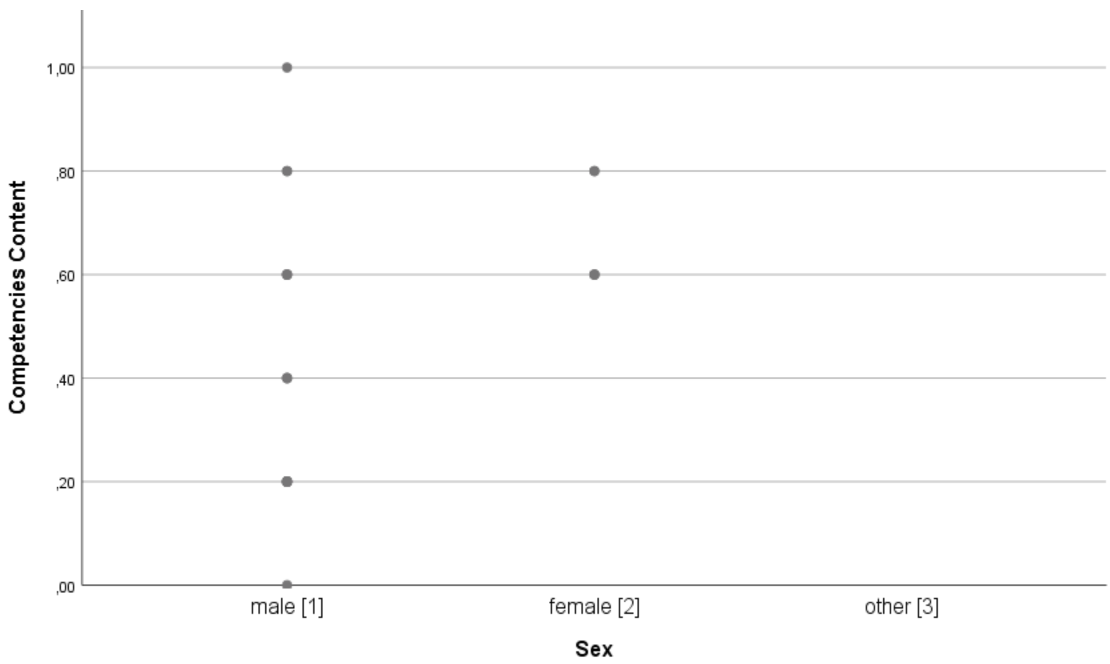


Figure 6.16: Scatterplot for the variables sex and competencies in the first survey of the *FLAT Duisburg-Essen* study.

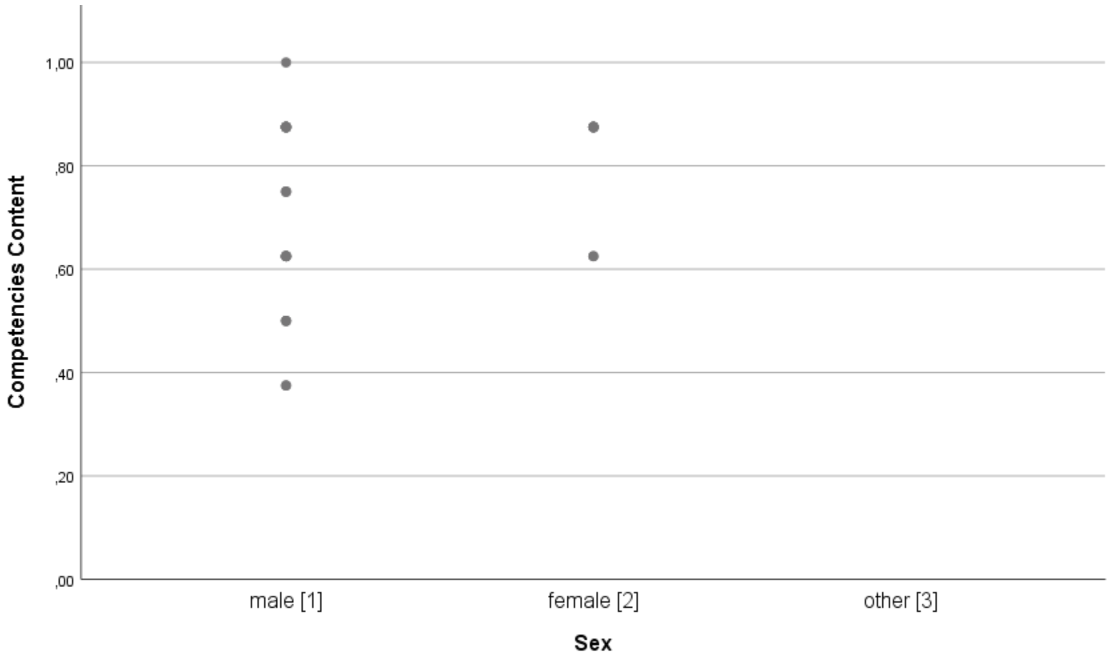


Figure 6.17: Scatterplot for the variables sex and competencies in the third survey of the *ReSyst Berlin* study.

For the variable *sex*, no significant correlations were found but in the three surveys

- *FLAT Berlin* survey 3 (Table B.23, $\tau = 0.310$, $p = 0.046$),
- *FLAT Duisburg-Essen* survey 1 (Table B.25, $\tau = 0.386$, $p = 0.045$) and
- *ReSyst Berlin* survey 3 (Table B.41, $\tau = 0.492$, $p = 0.007$),

suggestive positive correlations with the questions on the competencies on prior knowledge / the knowledge concerning the respective Learning Unit could be found. The possible answers on *sex* were male, female and other (which was seldomly used). Male was coded with 1, female was coded with 2 and other with 3 with the possibility to enter a self-chosen label in a follow-up question. The answers on competencies were summarized as percentages, and therefore could range from 0 to 1. As the "other" option for *sex* was used very rarely these correlations can be interpreted as females performing better in these questions than males. As this is a very interesting aspect it will be looked into more intensely. In all cases more male than female students participated in the studies, which also reflects the situation in the corresponding courses. The male/female ratio for these surveys varies, but in all three cases, there is a substantial amount of female students, as can be seen from the histograms for *FLAT Berlin* survey 3 in Figure 6.11, *FLAT Duisburg-Essen* survey 1 in Figure 6.12 and *ReSyst Berlin* survey 3 in Figure 6.13 – again, male sex was coded with 1, female was coded with 2 and other with 3. Interestingly, when e.g.

comparing the variable sex in *ReSyst Berlin* survey 3 in Figure 6.13 with the variable in the first survey of the same study in Figure 6.14, the male/female ratio did not change, where in the former there is a suggestive correlation with competencies and in the latter there is not. In all three cases where suggestive results could be found, a visualization of the results on competencies separated by sex (*FLAT Berlin* survey 3 in Figure 6.15, *FLAT Duisburg-Essen* survey 1 in Figure 6.16 and *ReSyst Berlin* survey 3 in Figure 6.17) shows that the results of the male participants are far more spread out over the range of competency results, whereas results for female participants are mostly high. These three suggestive results might have their origin in a broader range of male students choosing computer science as their subject, which was for a long time seen as a male-dominated area, whereas mainly high-performing female students choose such a subject. It would be very interesting to see if such a correlation could be found for the regular courses, or if the self-selection through the study influences this process.

The students were asked to assess whether they tend to use computers for learning (coded as 0) or for entertainment purposes (coded as 101). For the first survey of the *FLAT Duisburg-Essen* study (Table B.24), a significant negative correlation (τ = -0.429, p = 0.005) could be found with the *interest* scale, meaning that the interest was high when the students tended to use their computer more for learning than for entertainment purposes. This preference could mean that those students are very determined and interested and therefore very purposefully use the computer for learning. Apart from that, no clear tendencies for this variable were found. Most students probably use their computer for learning as well as for entertainment purposes.

The students were asked several questions to assess their abilities for self-regulated learning. For the first survey of the *FLAT Duisburg-Essen* study (Table B.25), a significant positive correlation ($\tau = 0.549$, $p = 0.001$) could be found with the content questions on prior knowledge. This means that those students that were able to learn self-regulated also had good prior knowledge. This is highly relevant, as self-regulated learning is an important factor for being able to use Learning Units like the ones constructed for this dissertation properly and at the right moments for it to benefit most, ideally improving exam results and general competencies. Apart from that, no clear tendencies for this variable were found, which might be due to other unknown variables influencing how much a student benefits from the Learning Units. For example, even a very good skill in self-regulated learning might not be helpful if there is no interest in the area.

For the questions on the computer affinity of the students, no overall clear tendencies could be found.

The self-assessment A slide bars on the respective first Learning Units (finite automata and pumping lemma for the *FLAT* studies, strong and weak bisimulation for the *ReSyst* studies) correlated positively with the *interest* scale four times. A significant correlation could be found in the second survey of the *FLAT Berlin* study (with self-assessment A, Table B.20, $\tau = 0.411$, $p < 0.001$). Additionally, suggestive correlations could be found in:

- *FLAT Berlin* survey 1 (Table B.18, $\tau = 0.182$, $p = 0.033$),
- *FLAT Berlin* survey 3 (Table B.22, $\tau = 0.326$, $p = 0.006$) and in
- *FLAT Potsdam* survey 1 (Table B.30, $\tau = 0.276$, $p = 0.044$).

The interest of the students was high when they also assessed themselves positively. To the best of the author's knowledge, no research on correlation of this QCM scale and self-assessment exists directly, but in [MH08], McMillan and Hearn discuss the relationship between self-assessment and motivation, stating that positive self evaluations encourage students to be more engaged. This could be seen as high interest being related to good self-assessment, even though self-assessment in this article is discussed in many more facets than the rather simple assessment used in this questionnaire.

Interestingly, significant positive correlations of these self-assessment A results with the respective questions on competencies could be found for the

- *FLAT Berlin* survey 1 (Table B.19, with competencies A, $\tau = 0.407$, $p < 0.001$) and
- *FLAT Berlin* survey 2 (Table B.21, with competencies content, $\tau = 0.338$, $p = 0.003$).

It is important to note here that the amount of questions on the topics concerned was considerably higher in this second survey (*FLAT Berlin* survey 2), yet there was a significant correlation. Additionally, in the second survey of the *FLAT Potsdam* study (Table B.33), a positive suggestive (and close to significant) correlation ($\tau = 0.553$, $p = 0.009$) with these questions on competencies could be found. Students in these cases assessed themselves positively when they also were able to answer the corresponding questions correct, which indicates a strong ability of self-assessment for the students. This is an interesting result, compared to the meta-study of Boud and Falchikov [BF89]. They concluded that students were able to assess themselves accurately, but mainly in later course years. In contrast to that, the students in the *FLAT* studies were freshmen. Additionally, a significant positive correlation ($\tau = 0.343$, $p = 0.001$) with the competencies on the second set of Learning Units (automata minimization and pushdown automata in this case) could be found for the *FLAT Berlin* survey 1 (Table B.19). The students that performed well on the second set of content questions also assessed their abilities for the first set of content questions as strong.

The self-assessment B slide bars on the respective second Learning Units (automata minimization and pushdown automata for the *FLAT* studies and fixed point theory for the *ReSyst* studies) correlated again positively with the *interest* scale in three cases. For the *FLAT Berlin* 3 survey (Table B.22), a significant correlation ($\tau = 0.430$, $p < 0.001$) could be found, and there were suggestive correlations for *FLAT Potsdam* 1 (Table B.30, $\tau = 0.340$, $p = 0.017$) and *FLAT Potsdam* 2 (Table B.32, $\tau = 0.559$, $p = 0.006$) surveys, where the latter is even very close to significant. This can be interpreted to mean that students with high interest assessed their abilities for this second content part positively.

Five suggestive positive correlations of the self-assessment B slide bars could be found with the corresponding questions on competencies:

- *FLAT Berlin* survey 2 (Table B.21, with competencies B, $\tau = 0.289$, $p = 0.017$),
- *FLAT Berlin* survey 3 (Table B.23, with competencies content, $\tau = 0.287$, $p = 0.026$),
- *ReSyst Berlin* survey 1 (Table B.37, with competencies B, $\tau = 0.260$, $p = 0.021$),
- *ReSyst Berlin* survey 2 (Table B.39, with competencies B, $\tau = 0.300$, $p = 0.047$) and
- *ReSyst Berlin* survey 3 (Table B.41, with competencies content, $\tau = 0.378$, $p = 0.015$).

It is again important to note that in the respective third surveys, the number of questions on these topics was considerably higher. These correlations can be interpreted to mean that when students performed well on those questions they also assessed their abilities as strong (or the other way round), similar to the self-assessment of the first Learning Units. The results on slide bars appear to be correlated considerably more often where the number of participants was high. Possibly, this relationship existed in general and could not be found in the other locations due to lower statistical power, where participant numbers were low.

For the question whether students tend to learn alone or rather in small or large groups, no clear overall tendencies could be found.

For the learning style scale concerned with *active and reflective learners*, no significant correlations with other variables could be found, but the tables show three negative suggestive correlations with the *challenge* scale:

- *FLAT Duisburg-Essen* survey 1 (Table B.24, τ = -0.355, p = 0.027),
- *FLAT Duisburg-Essen* survey 2 (Table B.26, τ = -0.929, p = 0.011),
- *ReSyst Berlin* survey 1 (Table B.36, τ = -0.234, p = 0.023).

The learning style scale is coded in such a way that negative values (up to -11) indicate a tendency of the learner to active experimentation and positive values (up to 11) indicate a tendency of the learner to reflective observation. These correlations can be interpreted to mean that the more students tended to active experimentation, the higher their experienced challenge was. The more students tended to reflective observation, the lower was their experienced challenge. As already stated, this can not be interpreted as a causal link between those factors. Felder and Silverman state that "[t]he reflective observers are the theoreticians, the mathematical modellers, ..." [FS02], which makes it plausible that in courses on these topics those students experience less challenge than those preferring active experimentation.

For the other scales on learning styles, no clear tendencies could be found, although it has to be pointed out that the scale on sensors and intuitors had a considerably larger amount of suggestive correlations with competency and QCM scales than any of the other learning style scales.

The QCM scales were correlated with the results on competencies. The only clear tendency could be found in the *FLAT Berlin* survey 1 (Table B.19) where the *interest* had a positive significant correlation ($\tau = 0.291$, $p = 0.002$) with the questions on competencies concerning the first Learning Unit on finite automata and the pumping lemma. Students with a high interest might already have had a larger amount of knowledge on these upcoming topics.

In addition to these correlations, the correlation coefficients and significance values for the ILS scale on visual or verbal learners and the question whether the students preferred explanations as text or video were computed. Only a small percentage of answers exists on the latter variable per survey. Therefore only the three largest studies were evaluated on this aspect. The values can be found in the Table B.42. No significant or suggestive values on this were found. As videos represent a mixture of visual and verbal content, this coincides with the underlying theories.

6.4.1 Results Overview

The most interesting results in this consideration of correlation between different variables are the aspect of female students performing better than males, which should be further investigated, as well as the self-assessment in combination with the QCM scale *interest* and the self-assessment in combination with competency results. If the self-assessment results would hold on larger scales, this could be very interesting for quick checks, e.g. in lectures on how the course is currently progressing. Concerning females outperforming males, it would be of most interest to find out if this holds for similar studies, what the underlying causes are and what possible factors are influencing this issue.

Another interesting result was that those students tending to active experimentation as a learning style experienced a higher challenge than those students with a tendency to reflective observation.

6.5 Additional Usage Statistics and Feedback

This section comprises three different ways of additional feedback and information on the Learning Units, namely the interviews that were conducted with several study participants, the follow-up surveys that were conducted for the studies in Berlin after the respective course exams had taken place, and an overview of Moodle statistics to get insight in the aspects of usage that are shown in such system statistics.

6.5.1 Interview Results

As a result of the low participation rates, interviews were conducted in all study locations to find out more about how students felt towards the Learning Units, about strengths and weaknesses of the Learning Units, and on what had motivated the students to participate. After a general introduction to the interviews and their circumstances, this section will first present the categories that resulted from the evaluation of the interviews using the qualitative content analysis, and afterwards the results. The students were asked to participate in the interviews on a voluntary basis. This participation was independent of the voucher raffling or payment. Where the students were interviewed in person, they were offered chocolate bars as a thank-you. For all studies, the students that had participated in the study were asked to be interviewed via the Moodle-platform. Interviews were done in person, via e-mail, chat or video chat. All spoken elements were recorded with the agreement of the interviewee and later transcribed. Again, participation varied strongly.

The number of interviewees in the different study locations can be seen in Table 6.9. The pre-processed interviews can be found in the digital appendix (Appendix A-MA772). The interview guidelines can be found in Appendix D.1.

Table 6.9: Interview participation.

Study	Number of Interviewees
FLAT Berlin	6
FLAT Duisburg-Essen	1
FLAT Potsdam	2
ReSyst Aachen	3
ReSyst Berlin	7
ReSyst Salzburg	1
	20

The categories were derived directly from the questions posed in the interviews, and as these were rather straightforward, the categories did not have to be refined further, only the category *possible non-participation reasons* had to be added. The first idea was that answers on the corresponding questions could as well be part of the category *motivation of participation*, but it was soon apparent that this would lead to confusing results.

The first category, **motivation of participation**, sums up why the students were taking part in the study itself, giving an interesting insight into the advantages of such an approach from the students' perspective. The second category, **were the Learning Units helpful**, is extremely close to the actual question asked in the interviews, and the answers were evaluated on an abstract level in a simple yes/no manner to get an idea of the general feeling of the students towards the Learning Unit. The third category, **usage**, contains answers on how much the students used the Learning Units. This is also evaluated on a very abstract level, honed down to five different answers. In the fourth category, **strengths of the Learning Unit**, students were asked what they liked about the Learning Units, which sums up those points that should be intensified for future developments. Category five, **weaknessess of the Learning Unit**, sums up what the students did not like about the Learning Unit, in order to be able to increase the number of students using them and to improve those units further. The sixth category, **bonus pages**, covers whether students have had access to the bonus pages at all and how they used them if they did. Category seven, **possible non-participation reasons**, sums up reasons why students might not have participated in the study, which can be guesses as well as reasons the students heard from their fellow students.

In the following, the results of the analysis as described in Section 6.1.4 for each of the categories will be presented. For **motivation of participation**, half of the interviewees named their interest in additional material as a motivation to participate in the study. Three of them participated because the lecturer asked them to. Several times students stated what can be summarized as their interest in *information on demand*, as one of the students in the *ReSyst Aachen* study called it, such as the possibility to learn interactively only, using material that is always accessible or having the opportunity to repeat the content. In the *FLAT Berlin* study, it was explicitly mentioned twice that the chair was doing very good work in their teaching and students wanted to support that. Apart from these smaller and greater accumulations, the answers were rather differentiated. Students participated for their chance to get the Amazon voucher, for the possibility to get direct feedback, out of general interest, to perform better in the exam, or to support research in general. Especially the interest in additional material and information on demand are rather interesting because they are both crucial aspects of the general idea behind the approach of this dissertation.

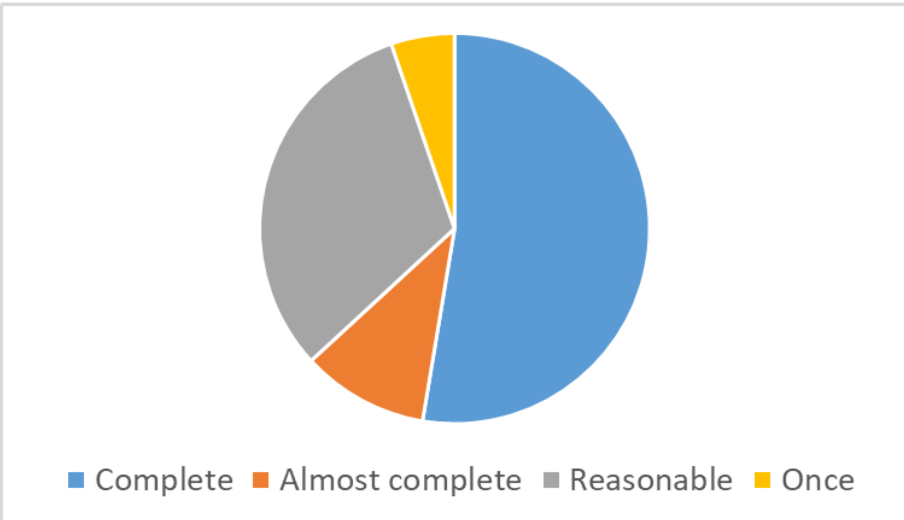


Figure 6.18: Percentage of usage of the Learning Units as reported in the interviews.

For the next category, **were the Learning Units helpful**, it is important to state that, as the interviews were only semi-structured, not all questions were posed to all of the twenty interviewees. Therefore, not everyone was asked this as an explicit question. However, for all cases when students were asked it directly or stated something very close to such a statement, it was added to this category. Fifteen students were counted in one of these ways, and all answers were *yes*. It is of course very probable that students that did not like using the Learning Units dropped out of the study earlier or were not interested in being interviewed. Nevertheless, these interview results encourage further usage and development.

The results of the category **usage** are visualized in Figure 6.18. Nineteen students were asked the question on how much they had used the Learning Units. On this abstracted level, 53 percent answered something to the effect that they had used the whole Learning Unit, 11 percent used almost the whole Learning Unit, 32 percent used the Learning Unit for a while but not to such an extent as in the previous answers, which is here called *reasonable*, and 5 percent used the Learning Unit only once. Again, students that did not like the Learning Units probably had no interest in participating in the interviews.

In the category **strengths of the Learning Unit**, the main strength mentioned (ten times overall) was the possibility to choose between text and video. Eight times, the possibility to get information on demand was mentioned as a strength, and three times the ability of getting immediate feedback in exercises. Twice students mentioned that they saw it as a strength that the content fitted the course so closely. This was preferable to using alternative sources on the internet. Additionally, twice it was mentioned that ungraded exercises were seen as a strength of these Learning Units, matching the intentions in creating them. Many reasons concerning the content seemed to be important to the students: They liked the conversational style, the completeness of the explanations with as little need for preliminary knowledge as possible and, as mentioned three times, the gradual approach of the explanations. Another cluster of answers concerned the structure: Twice students stated that the mixture of content and exercises was a strength, the good general structuring and the introductory exercises were mentioned as well. All these answers indicate that at least for these interviewed students, the Learning Units have worked as they were intended.

The issues mentioned the most in the category **weaknessess of the Learning Unit**, eight times altogether, concerned usability issues with Moodle: Students could not find the way to repeat a particular exercise. They did not get an overview when they were already working on content, or had problems with the e-mail delivery as they could not answer directly on forum posts. In some cases, their progress was not registered when they worked on several open browser tabs. Five times, students unspecifically mentioned that they had found mistakes in the exercises, four students mentioned problems in the LaTeX formatting, which could be typos as well as problems with rendering the formulas. This issue was tested and controlled several times to improve this part of the presentation. Three students stated that a weakness of the approach was the equal weighting of the different topics as they would have preferred more content on those topics they had more problems with. As these preferences are not equal for all students, such an imbalance was not yet considered for the Learning Units to allow everyone to deepen their understanding in those topics that suit him or her best. Three students had found spelling mistakes in the Learning Units. This issue is currently being examined by re-reading the explanations with a strong focus on spelling mistakes. Two students saw weaknesses concerning the videos: one of them did not like the content of the video being identical to that of the text, and the other that the videos were opened in an embedded frame. The student would have preferred instead to be linked directly to Youtube. This possibility is being considered, but as opening the videos directly on Youtube might distract the students, possibly a better solution has to be found. One student saw it as a weakness that the material was only supplementary and did not cover all content. One student had problems with the necessity to be online to use the units. This is an interesting issue for further improvement of the Learning Units, as generating a reduced version as static output could be useful. With the existing tools for Moodle, this is, to the best of the author's knowledge, not yet possible, as the formulas were not displayed correctly in tests. Another student mentioned that a problem with the approach was that there was no option to get answers to individual questions directly as it is possible in a lecture. This could have been at least partially solved if students had used the discussion forums in the Learning Units, but, of course, the asynchrony of such a response is nevertheless a slight drawback of such approaches. A lot of these issues concern the usability and design of Moodle in general, which gives rise to the question if alternative platforms could be used or implemented for future developments of these Learning Units. Then again, Moodle is a very powerful platform while platforms with equal functionality are scarce, and the development of the Learning Units would have been severely more complex if aspects such as registration, course management, role management, learning paths and many more had to be implemented.

The results in the category **bonus pages** were mixed. The corresponding question was only added to the guidelines after a few interviews. Therefore, thirteen students have answered it. Of these students, many seemed to have been motivated to unlock the bonus pages. All but one student had accessed them. Of these, only two had looked into the exercises beyond the level of thinking about the question shortly. The hurdle seems to work for these students but possibly more interesting or fascinating content would be useful to keep this motivation awake. Alternatively, as one student suggested, solution approaches could be added to the bonus pages directly or in the form of links to other sources to give them a more direct opportunity to verify their initial thoughts or their work on these questions.

The reasons mentioned in the category **possible non-participation reasons** are to a large extent guesswork, of course, but it is nevertheless an interesting way to find out possible reasons why students did not or not fully participate. The main reason that was mentioned eight times was that students often have problems with their self-organization and therefore probably had forgotten to participate in time to meet the deadline. Seven times students mentioned that their fellow students probably did not have any capacity for more work in their semester schedule. Four students explicitly mentioned that students are lazy as the reason for the low participation. Other reasons mentioned twice respectively were a lack of excitement of students towards the study and therefore not enough interest, that the incentives might not have been interesting or big enough, and that students already had enough material to feel comfortable with. One student mentioned that other students possibly were too competent on the subject to be interested in such Learning Units. Interestingly, the reasons mentioned the most had nothing directly to do with the Learning Units, but this could also have been influenced with the interviewer being the same as the one that had conducted the study. The statement on the lack of excitement is probably important even though it was only twice mentioned explicitly. More excitement towards the study might have made the students overcome problems of self-organization as well as capacity problems. It will be interesting to see if the Learning Units will be used more intensely in the future, when they can be accessed without deadlines or surveys to answer.

6.5.2 Follow-Up Surveys

It is a rather common argument that support like the one constructed and evaluated in this dissertation is mostly used by high performing students that would not actually need such support. This is assumed despite the support being designed for all the students or especially with struggling students in mind as the target group. As already stated, the students that participated in a study had the possibility to use both Learning Units relevant to the course after the study was finished, up until the exam took place. The only exception is the study at the *ReSyst Aachen* where this idea was not yet used as an incentive. For the two largest studies, *FLAT Berlin* and *ReSyst Berlin*, the study participants were asked to fill out short additional surveys concerning their UX, their usage of the Learning Units and their grades. This section will concentrate on the latter as well as their self-assessed hours of usage.

For both *FLAT* and *ReSyst*, after consultation with the Data Protection Official of Technische Universität Berlin, grade ranges were set up after the exams were finished to make sure that students could not be identified based on their stated grade. A total of 50 points could be reached in the written *FLAT* exam, and the best grade in the *ReSyst* oral exam was 1.0, as can be seen in Table 6.10.

Table 6.10: Grade ranges for the *FLAT* and *ReSyst* course exams in Berlin.

FLAT	Key	*ReSyst*
50 - 41	**A**	1.0 - 1.3
40 - 31	**B**	1.7 - 2.0
30 - 21	**C**	2.3 - 2.7
20 - 11	**D**	3.0 - 3.3
10 - 0	**E**	3.7 - 4.0
	F	5.0

In Table 6.11, the comparison of the range distributions of the 438 students that received a grade in the exam and the 25 students that filled out the questionnaire can be seen. According to the platform logs, 30 students had used the Learning Units to prepare for the exam. 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 part of the course material tested in the exam, an improvement of the course ranges due to the Learning Units is, although not impossible, not detectable in any reliable way.

Table 6.11: Distribution of grade ranges in the end of term exam of *FLAT Berlin*.

	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

In Table 6.12 the comparison of the range distributions of the 90 students that received a grade in the oral exam and the seven students that filled out the questionnaire can be seen. 17 students had used the Learning Units after the study was finished. Here as well – and as expected –, the grade ranges are better in the post-questionnaire than in the exam. The 25th percentile and median are both shifted one range upwards where the 75th percentile and maximum are both equal. It seems probable that students that had failed the exam were not in the right mood to fill out surveys on their outcome.

Table 6.12: Distribution of grade ranges in the end of term exam of *ReSyst Berlin*.

	Course Ranges	Post-Questionnaire Ranges
Minimum	F	D
25th percentile	E	D
Median	D	C
75th percentile	B	B
Maximum	A	A
n	90	7

Even though the students' answers to the questionnaires in both cases suggest that the students using the units had a tendency towards 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.

In Section 6.3.1, results on the question for the number of hours the students had used the Learning Units were presented. The same question was also part of the follow-up surveys. Again, the scale was 1 (less than one hour), 2 (one hour to five hours), 3 (five hours to ten hours) or 4 (more than ten hours). The result over all studies was a mean value of 1.91 with a standard deviation of 0.54 and a median of 2.

For the *FLAT Berlin* course, the mean value of those students that participated in the survey (n = 25) was 2.24 with a standard deviation of 0.59 and a median of 2.

For the *ReSyst Berlin* course, the mean value of those students that participated in the survey (n = 7) was 2.86 with a standard deviation of 0.83 and a median of 3.

In both cases, the values are higher than the original average value, for the *ReSyst Berlin* course both the mean and the median even fall into the category of five hours to ten hours of usage.

Overall, not many students used the Learning Units after they were opened to all study participants in both courses. This might be because of too little interest, or because they were not advertised in any way beyond one Moodle forum post. It will be interesting to see how students use the units when they are part of actual courses, without limitations to surveys and deadlines.

6.5.3 Moodle Statistics

The following section will give an overview of the Moodle logs for all six surveys. There are several reasons to consider why this analysis will be kept rather simple. One reason is that the Moodle logs in their basic form only log a rather reduced repertoire of actions like whether a person has viewed a certain page or submitted a certain exercise. These logs are not extremely conclusive, considering the actual behavior of the students. The second reason is that in the interviews, several students stated the usability issue of their progress not being monitored by Moodle if they had used one browser with several tabs open. This leads to the assumption that their actual behavior was not logged properly as well. Another reason is that in the analysis, it was assumed that students might have used the login of fellow students. This assumption originated from their answers in the survey. Therefore some of the students were excluded. These logged actions are not easy to exclude from an analysis of the logs. The final reason is that the focus of this dissertation is not on this kind of analysis. For all these reasons, the analysis will only be kept short.

Table 6.13: Analysis of all interactions based on Moodle logs.

Study Location	No. of Participants	No. of Interactions	Min / Max	Interaction Mean (Std. Deviation)
FLAT Berlin	51	11519	2 / 668	225.86 (152.34)
FLAT DUE	9	884	1 / 406	98.22 (130.56)
FLAT Potsdam	21	3541	5 / 498	168.62 (163.14)
ReSyst Aachen	4	1396	266 / 462	349.00 (73.43)
ReSyst Berlin	36	12989	1 / 1232	360.81 (290.45)
ReSyst Salzburg	6	2146	34 / 783	357.67 (255.93)

The logs of the Moodle courses were cleaned for interactions of system tests, interactions of the lecturers trying out the Learning Units, and similar "noise". Afterwards, 32,475 interactions remained over all six studies. Table 6.13 shows the number of different accounts that worked on the Learning Units, the number of interactions, the smallest and largest number of interactions of one user for all the studies and the mean and standard deviation over all users. As the groups were separated, no account interacted with both Moodle courses of one survey. The number of participants is in almost all cases smaller than the group size. Of course, the number of interactions differs strongly with different numbers of participants, but not in all cases. This can be seen for the *ReSyst Salzburg* study, which has less participants but more interactions than the *FLAT Duisburg-Essen* study. The *ReSyst Berlin* study also has about one third less participants than the *FLAT Berlin* study, but more interactions. This study is also the only one where a single participant interacted more than 1000 times with the platform in the course of the study. The interaction mean is lowest for the *FLAT Duisburg-Essen* study with a huge standard deviation and, interestingly, highest for all three *ReSyst* studies, although the standard deviations for Berlin and Salzburg are very large, which suggests much variation in the data. It is possible that the more complicated topics of the *ReSyst* courses or the different personal learning developments of the students lead to these differences.

Table 6.14: Analysis of lesson and test interactions based on Moodle logs.

Study Location	Lesson (Min / Max)	Lesson Mean (Std. Deviation)	Test (Min / Max)	Test Mean (Std. Deviation)
FLAT Berlin	0 / 382	143.35 (90.50)	0 / 377	67.86 (69.97)
FLAT DUE	0 / 201	49.44 (63.77)	0 / 187	40.33 (71.98)
FLAT Potsdam	3 / 215	90.90 (74.60)	0 / 279	66.95 (86.10)
ReSyst Aachen	172 / 290	230.00 (45.60)	78 / 141	97.50 (25.50)
ReSyst Berlin	0 / 874	240.17 (204.36)	0 / 287	97.19 (81.06)
ReSyst Salzburg	14 / 451	221.83 (148.82)	19 / 291	108.17 (93.93)

Table 6.14 shows statistics concerning interactions on lessons and tests. Both exclude each other. Lessons, as well as tests, were also part of the interaction overview in Table 6.13. This more specific table shows the smallest and largest numbers of interactions for one participant on the lesson module, the mean of interactions with this module and the same statistics for tests. Tests are the exercises which were not integrated into lessons (i.e. tests are not surrounded by content). With 874 lesson interactions, the *ReSyst Berlin* study is by far the one where one participant interacted most intensely with the lessons. The mean of this study considering lessons is also the highest, albeit with a huge standard deviation. The lesson means for the *ReSyst* studies are all higher than for the *FLAT* studies, showing the same effect as when all interactions were considered. Except for the maximal values for single participants where the *FLAT Berlin* study is leading, the same effect can be seen for tests, again in combination with large standard deviations.

Overall, fewer students seem to have used the Learning Units than taken part in the surveys, but as can be seen from the logs, there were students that used the Learning Units very intensely, which leads to the assumption that those students enjoyed using the Learning Units.

6.5.4 Results Overview

Overall, the principal result of the interviews was that the main reasons for students to participate were to get additional material in general and information on demand, independent of daytime or lecture times. Overall, they assessed the Learning Units as helpful and saw the possibility to choose between text and video and the information on demand as the main strengths. The main weaknesses mentioned were concerning the usability of Moodle, technical problems and (unspecified) mistakes in the Learning Units. Most students wanted to unlock the bonus pages, but did not or hardly use the content on these pages.

The follow-up surveys lead to the conclusion that students of a smaller grade range than the whole course participated in the studies, but fortunately a still fairly large range.

The main result considering the Moodle statistics is that the *ReSyst* studies lead to far more interactions with the Learning Units which might be due to the more complex topics, the different course years of the participants (in contrast to the *FLAT* studies) or other unknown factors which still have to be worked out.

Chapter 7

Conclusion and Outlook

Up to this point in the dissertation, the approach for the Learning Units was created. Based on this approach, the Learning Units were constructed, alongside an evaluation instrument. These steps can be seen as the central contributions of this work. Six studies were conducted at five different universities to evaluate the approach considering motivation and competencies. Additionally, the UX of the Learning Units was tested and interviews were conducted with participants to find out more about their usage of the Learning Units.

This chapter will begin by summarizing and interpreting these evaluation results, followed by an overview of the lessons learned in the process of both constructing the Learning Units as well as evaluating them. Generalizability is discussed for the study results. Afterwards, possibilities for further research are discussed. In the end, an overview of how the Learning Units are used beyond the studies is given. This overview is combined with possibilities for further usage of these specific Learning Units as well as the general approach.

7.1 Summary of the Results

This section will summarize and discuss how the findings presented in Chapter 6 could be used to further improve the Learning Units and the evaluation instrument.

Overall, the results indicate that the Learning Units were a helpful approach for those students that used them.

In accord with the ideas of design-based research, as presented in Chapter 2, the results of the assessment throughout the studies will be used for further improvement of the Learning Units to enable the sustainability of the approach. Where results indicate interesting or unusual connections of variables, hypotheses will be presented as a basis for further research.

7.1.1 Motivation

On motivation, the findings presented in Section 6.2.1 were rather ambiguous. *Interest* seemed to be slightly reduced in the *FLAT* studies (the combined results of the *FLAT Berlin* and *FLAT Potsdam* studies), whereas, in the *ReSyst Berlin* study, no tendencies could be found. The hypothesis on this scale was that it would not be affected by using the Learning Units. For *probability of success*, no tendency was found in the *FLAT* studies, but there was an increase by using the Learning Unit in the *ReSyst Berlin* study. The latter fit the corresponding hypothesis. For *anxiety*, no tendencies were found, where the hypothesis was that the value of the scale would decrease by using the Learning Unit. In the *FLAT* studies, the *challenge* seemed to increase by using the Learning Unit, whereas no tendency was found for the *ReSyst Berlin* study. All these tendencies were neither suggestive nor significant. No new hypotheses will be derived from these results, but further research is necessary to get a clearer insight into the relation of motivation and the usage of such Learning Units. Possibly, larger studies could give a more meaningful image of this relation. Another possibility is that this ambiguity was related to the QCM as a tool for measuring the learning motivation in the given scenario. Results might be more accurate in a pencil and paper version of the QCM, without distractions that can occur when filling out such questionnaires on a computer or mobile device. Alternatively, the development of a renewed version of the QCM might be necessary for such scenarios.

7.1.2 Competencies

The overall results on competencies presented in Section 6.2.2 indicated that the Learning Units helped the students in this area and improved their learning. There was even one statistically suggestive ($p < 0.05$) difference between groups in the *FLAT* studies. In the second survey, group A performed to a suggestive level better in the content questions after using the first Learning Unit. A detailed competency model for the concerned areas, combined with measuring instruments to test whether specific competencies were reached, would be useful. Additionally, such an instrument could enable testing whether these findings involve all the desired competencies that were presented in Section 4.1. Such an instrument would also enable instructors to give more detailed feedback depending on students' answers which competencies already have been mastered to which degree, and which competencies still need more training. Interestingly, where learning outcomes are considered, the results of the meta-studies of Bernard et al. [BBS+14] as well as Means et al. [MTMB13] are similar to the ones in this dissertation.

7.1.3 Usage and User Experience

Concerning UX, as presented in Section 6.3, the Learning Units were evaluated positively on the scales *attractiveness*, *perspicuity*, *efficiency*, *dependability* and *stimulation*. Users had a good general impression of the Learning Units and found it easy to use them without unnecessary effort. The users felt in control of the interaction with the Units and were motivated to use them. Especially that the users felt in control of working with the Learning Units (represented on the scale *dependability*) with their clear organization and structure is seen by the author to be an important aspect for a learning platform. The only scale with a neutral evaluation was *novelty*. The result on *novelty* is to be expected, as nearly all students know learning management systems like Moodle in one way or the other and are familiar with the general ingredients used in this approach. The neutral evaluation of *novelty* can be seen as a positive result, as a completely new learning environment could also have distracted and irritated the students. Furthermore, the results on UX were compared to a large benchmark of other study results using the user experience questionnaire. In this comparison, the UX showed results above average for the scales *attractiveness*, *perspicuity* and *stimulation*. Results below average were found concerning *efficiency*, *dependability* and *novelty* despite the positive general evaluation on the first two scales. Overall, the system might not have been spectacular enough to create excitement amongst the students. However, it can be called into question how spectacular a learning environment should be that is intended for regular use. In contrast to games or websites with the intention of pure entertainment, the Learning Units are meant to be reliable and useful. The idea was to integrate as little unnecessary elements as possible. Therefore, the focus of further development should lie on improving the general UX and especially navigation, rather than on introducing features simply to impress with design or possibly distracting irrelevant features. Further improvements where the user interface and the whole learning experience are concerned can be useful, even though the general evaluation was positive. In the open questions, most negative points related to the general overview, navigation and the interface as well. On the positive side, students wished for more content and more questions to work with, which indicates that the approach appeared useful to them. Possibilities to improve the UX could be:

- improving navigation by the option of showing the existing graph of the lesson with the current position and the recent path marked,
- adding links to the vertices in this graph to the corresponding material,
- showing the hurdle for the bonus pages and the progress towards it more explicitly,
- adding further tutorials for platform usage and
- adding the possibility to choose whether text or videos are presented first whenever content is shown.

7.1.4 Correlation with Further Variables

In Section 6.4, the correlation between variables was examined. This section will summarize the most important results.

Concerning sex, women performed demonstrably better in several studies on the content questions, which is interesting in an area that is often seen as dominated by men, as, e.g. discussed by Bergner [Ber15]. This leads to the following research hypothesis:

- (NH1) Female students outperform male students (in studies) on the subject of theoretical computer science.

It would be very interesting to find out whether this hypothesis holds for other studies in this area as well, and what possible factors influencing this are. Possibly, this result occurs based on some form of self-selection either for the computer science study program or for the participation in such a study. High interest of the students was correlated with positive self-assessment on the content, which leads to the research hypothesis:

- (NH2) Positive self-assessment correlates positively with interest of the students.

Additionally, positive self-assessment correlated with a good performance on the content questions in several cases. Students seem to have assessed their abilities appropriately. This does not lead to a new research hypothesis as this is basically in line with the literature in this area as discussed in Section 6.4, even though with a stronger focus on students in later course years. Another interesting correlation could be found concerning learning styles. Students tending to active experimentation perceived the challenge as high, and vice versa, students preferring reflective observation perceived the challenge as low. A possible explanation might be that this content is rather abstract and theoretical. Students that prefer active experimentation have more difficulty with learning it appropriately than those preferring reflective observation. From this correlation, the following new hypothesis is derived:

- (NH3) The learning style tendency towards active experimentation is positively correlated with the perceived challenge for content on theoretical computer science.

7.1.5 Interviews

The interview results (Section 6.5.1) showed that the interviewees used the Learning Units rather intensely. As students that did not like using these Learning Units probably had no interest in being interviewed, the results of the interviews can not be interpreted to be valid for the whole group of study participants. Nevertheless, the results are insightful. The main motivations for using the Learning Units were getting additional material and having information on demand, which are two of the key points of the concept of the Learning Units. The Learning Units were seen as helpful, with its strengths being the choice between text and video, having information on demand, and getting direct feedback. Weaknesses were mostly usability issues and problems with navigation on the platform. The bonus pages seem to have been a motivational goal as intended, yet the actual content of these bonus pages was not of much interest to these students. It will be interesting to investigate whether this depends on this content, or if the interest is generally lower once the bonus is unlocked. The main reasons stated for other students not participating were problems of self-organization or the lack of further capacity in students' schedules.

7.1.6 Follow-Up Surveys

The follow-up surveys, as presented in Section 6.5.2, showed that students that used the units did not represent the full performance range of the course, but still a large part of it. For both the *FLAT Berlin* and the *ReSyst Berlin* study, no students of the lowest grade ranges participated in the follow-up surveys. The assumption was that those students did not participate in the main study as well, as only the participants were asked to answer the follow-up survey. Another possibility is that those students of the lowest grade ranges simply were not interested to answer the follow-up survey after the exam.

7.1.7 Moodle Statistics

When analyzing the Moodle statistics in Section 6.5.3, the numbers of interactions were higher for the *ReSyst* courses, even though there were fewer participants. Possibly students were better organized due to the advanced state of their degree program, and therefore used the Learning Units more intensely or had more interest in it due to the higher complexity of the content. From this analysis, two interesting further research hypotheses are derived:

- (NH4) Self-regulated usage of a multimedia-based Learning Unit increases for more challenging content.
- (NH5) Self-regulated usage of a multimedia-based Learning Unit increases when students are more advanced in their degree program.

7.2 Lessons Learned

In this section, conclusions drawn from the process of creating and evaluating the Learning Units will be discussed.

7.2.1 Creating the Learning Units

When constructing such Learning Units, it is useful to have an in-depth understanding of problems students have when learning the content. In the case of the Learning Units presented in this dissertation, the author had had experience in teaching tutorials and creating exercises for a *FLAT* course as well as for a *ReSyst* course. Both courses had taken place at Technische Universität Berlin. In the semesters before these studies were conducted, the author was giving tutorials and creating exercises on both courses, creating written exams for the *FLAT* course and working on their grading. Additionally, being the recorder for many oral exams on the *ReSyst* course content helped the author in gaining insight into typical problems students experienced. This helped immensely in knowing the hurdles on the way to learn the content. Another great help was the exchange on this with other research and teaching assistants and the lecturer for these courses in Berlin, Uwe Nestmann.

Creating the Learning Units worked rather well in general, as the author had already had several years of experience in creating learning videos in the same area (insight into this process can be found in [NW14]) and was experienced in using Moodle as well. Even though the approach is very clearly structured and uses existing resources, creating such Learning Units takes effort. This is, without doubt, a hurdle for instructors with limited time, even if they see them as being useful. Creating text and images, recording and cutting video and the respective sound, and compiling exercises that are interesting, but still suitable as single-choice or multiple-choice questions, however, takes up time.

Overall, such an approach might have the problem that it is useful in general, but the material is badly or uninterestingly phrased. The aim was to avoid such a situation by conducting a formative evaluation with lecturers, research assistants and students participating. As neither the interviews nor the open questions indicated such major problems, the assumption is that this was not the case for the Learning Units.

7.2.2 Evaluating the Learning Units

Concerning the evaluation of the Learning Units, several aspects could have been improved. Using SoSci survey as platform for the surveys had many advantages, as surveys can very easily be created and tested, and data can be exported in different formats, e.g. for SPSS, R or Excel. Separating the surveys from the Learning Units, however, lead to problems where the pseudonyms were concerned. Some students answered the surveys on SoSci survey, but their pseudonym could not be found in Moodle and vice versa. Implementing the surveys directly in Moodle probably would have been advantageous in this regard.

For the use of the pseudonyms, one or more examples next to each item would have been preferable, as many of the pseudonyms could not be assigned in the analysis even though the rules for creating the pseudonyms were stated very clearly.

Asking the students to fill out the first questionnaire directly in the lecture would probably have improved participation rates strongly. This was not possible due to the extensive questionnaire, which took about 15 to 20 minutes to be filled out. Waiting until (almost) everyone had filled out the questionnaire would have used too much time of the lectures, where students already often struggle and might need time for more explanations. It would have been useful to exclude the ILS questionnaire on students' learning styles, as this would have considerably reduced the time for filling out the questionnaire, and allowed for the possibility to have it filled out in the lectures. Even though it is interesting to learn more about the target group based on their learning styles, this trade-off was disproportionate, as learning styles were not a large focus of this work.

7.2.3 Choices of Platform and Material

An important issue is the question of the platform used. Moodle was chosen for many reasons, especially for its large body of functionality, which simplified conducting the studies immensely, and for being an open source platform. As discussed in the previous section on the UX scale novelty, the approach was possibly not very spectacular for the students, where another platform or an enrichment of Moodle with further features like mini-games on the content or similar motivational material might have been. These could as well have easily caused distractions for the students and were therefore not considered.

The choice to use the *ReSyst* material was in hindsight also not ideal for the chosen evaluation scenario. Most courses on these topics turned out to be courses in master computer science degree programs, where course sizes are usually rather small. The main idea behind the choice of this material was that testing the concept of the Learning Units with a basic and an advanced course would give interesting insights, which it did in many ways. Such small course sizes, however, are impractical for quantitative evaluations and therefore, a different choice of topic might have been preferable.

7.2.4 Participation

An important issue which has already been discussed in literature on other educational approaches in computer science is that it is not easy to get students to use educational tools. An example for such a discussion can be found by Naps and many colleagues on the issue of visualization tools in computer science education in [NRA+02].

Similarly, it is important to motivate students to try out the Learning Units to get them interested. Improving the advertisement for the Learning Units, possibly by giving the students access to a different – completely accessible – Learning Unit on a course topic to get familiar with the concept, a period for registration longer than one week, and several more discussions of the Learning Units in the lectures could have improved the participation rate. So could have stronger incentives, like money for participation, some other kind of incentive for every participant or a significantly better grade in the course for participating fully in the study.

7.3 Generalizability

The results can not be generalized. The studies provided interesting insights and possibilities for further development of the used approach. Several similar tendencies repeatedly appeared in different study locations, but the results were not significant. Only on competencies, a suggestive difference could be found for survey 2 of the combined *FLAT Berlin* and *FLAT Potsdam* studies. The group that had recently used the Learning Unit had a suggestive advance in contrast to the other group that had not. That not more suggestive or even significant results were found might be because more effects do not exist on these issues, but also due to the low statistical power of the studies (as discussed in Section 6.1.2). It can also not be ruled out that some of the tendencies found were caused by sampling variation. The participants of the study were an interesting subgroup of the course participants but, as indicated by the results of Section 6.5.2, not a representative one. Overall, the results can neither be generalized for the population of computer science students or students in general. Even generalizing the results to the whole courses in which the studies took place can not be done safely. To achieve such an amount of generalizability, the studies could be repeated in an improved way, taking into account the considerations of Section 7.2 or making the participation obligatory to achieve a higher statistical power. As such an approach can be seen as ethically problematic, an individual possibility to exclude data from the analysis would be necessary in such a case. Obligatory participation might also create some amount of aversion against using the Learning Units or to filling out the surveys properly.

7.4 Further Possible Development Steps

This section is meant to give an overview of interesting aspects and possibilities of development of the Learning Units. That could enable a wider variety of scenarios for using the Learning Units, and also create new research scenarios.

- Learning Units could be further differentiated to include more complex and challenging tasks. This might include tasks with open answers to be corrected by lecturers or fellow students, or tasks that need complex solutions on paper where only the result (or a relevant aspect of the result) is tested via multiple-choice on the Moodle platform.

- Moodle lessons could be exported to a PDF or HTML document containing the different hyperlinks in-between pages, ideally either linking the videos or ignoring the lesson pages concerning videos altogether. Such an export would allow students to use the Learning Units at all times, in trains for example, where networks are not always working properly.

- More different types of exercises could be used for a larger variety when practising with the Learning Units, especially integrating tools for automata visualization like JFLAP.

- Bonus pages could be improved with solution approaches or a completely other type of interesting content for the students, e.g. ideas for applications of the content, mini-games or even more complex content questions.

- Using further approaches, it could be analyzed whether the insight holds that the *ReSyst* Learning Units seem to lead to more interactions.
- The approach could be tested for its accessibility and how to improve this. As most of the approach is realized using basic Moodle features, the general development of Moodle towards accessibility is important. The buttons that were added to the lesson pages use tags to make them accessible with screenreaders. However, formulas, and especially images of labeled transition systems are still open problems in that direction.

7.5 Further Research Possibilities

Further research could either be conducted using the existing Learning Units or after further development as presented in the preceding section. As discussed in Section 7.3, such research could on the one hand be a new version of the studies conducted for the evaluation in this dissertation, in order to further deepen the understanding concerning the current research questions, in line with the ideas of design-based research. On the other hand, it could include one or more of the following ideas:

- In studies on learning styles, it would be interesting to analyze whether there are always considerably more visual than verbal learners, as in the presented studies, and how this might relate to the choice of degree program.
- In the evaluation, the general impression was that the level of anxiety in the QCM questionnaire was higher for repeaters. This could be tested even without the Learning Units, by merely creating groups of repeaters and non-repeaters, handing them exercises on course content and, as the QCM is typically used, asking them to think about how they would solve such exercises, followed by asking them to answer the QCM questionnaire and comparing results.
- Research could be conducted that looks further into whether the outcome that females performed better in several of the studies holds from a more general perspective. On this aspect, analyzing the exam results for courses like the ones the studies were conducted in would be interesting, as well as conducting qualitative or quantitative studies comparing the learning process for different genders to get more insight into hypothesis NH1 ("Female students outperform male students (in studies) on the subject of theoretical computer science.").

- Further investigation on how self-assessment and interest are related, as stated in hypothesis NH2 ("Positive self-assessment correlates positively with interest of the students."), would be very insightful, especially if this holds for whole courses or all lecture participants. As both self-assessments and the QCM are very short, this could be tested for lectures as well as exams or, e.g., as optional homework questions. Depending on the direction of such a relation, it could be useful to work towards raising the interest of the students towards the course or improving their self-assessment abilities.

- In a similar or even related approach, students with a learning style tendency towards active experimentation could be interviewed regarding their typical learning process and their experience concerning theoretical computer science. This could help to confirm or refute hypothesis NH3 ("The learning style tendency towards active experimentation is positively correlated with the perceived challenge for content on theoretical computer science.").

- The research hypotheses NH4 ("Self-regulated usage of a multimedia-based Learning Unit increases for more challenging content.") and NH5 (Self-regulated usage of a multimedia-based Learning Unit increases when students are more advanced in their degree program.) are linked. To further investigate these areas, the Learning Units constructed and evaluated in this dissertation could be used with altered surveys, containing more detailed questions on the reasons why students used these Learning Units (e.g. not being able to follow the course, having advanced abilities concerning self-regulated learning, etc.).

- The creation and validation of a competency model for the different areas of theoretical computer science, along with measuring instruments for these competencies would be a very useful research approach to deepen the understanding of the differences and commonalities of these competencies. Additionally, for studies as the ones presented in this dissertation, it would refine the measurement of changes in the learning process.

7.6 Consolidation and Reusability

As the Learning Units were constructed with the aim to help students learning, the Learnings Units will be further implemented in courses beyond the evaluation discussed in this dissertation, hopefully creating a sustainable platform to help students with aspects of theoretical computer science.

This usage starts in the summer semester 2019 where the *FLAT* units are used in a course at Universität Duisburg-Essen and the *ReSyst* units are used in a course at the Technische Universität Berlin, with more to follow.

Table 7.1: Analysis of all interactions based on Moodle logs after opening the Learning Units for two courses.

Learning Units	No. of Participants	No. of Interactions	Min / Max	Interaction Mean (Std. Deviation)
FLAT	13	998	4 / 294	76.77 (99.13)
ReSyst	46	17851	4 / 1994	388.07 (471.40)
	59	18849		

Table 7.2: Analysis of lesson and test interactions based on Moodle logs after opening the Learning Units for two courses.

Learning Units	Lesson (Min / Max)	Lesson Mean (Std. Deviation)	Test (Min / Max)	Test Mean (Std. Deviation)
FLAT	0 / 252	53.00 (76.85)	0 / 96	16.92 (32.82)
ReSyst	0 / 1648	290.13 (371.07)	0 / 346	75.70 (93.79)

Several students in Berlin explicitly reached out to the author, thanking for the Learning Units and emphasizing that the Learning Units were helpful to them. After the first semester in these two courses, 18,849 student interactions[1] had been logged in the four Learning Units. Table 7.1 gives an overview of the Moodle logs after this first semester considering interactions, Table 7.2 gives an overview of this data grouped for lesson and text interactions. Again, the data are extremely spread out in-between the students, as can be seen by the minimal and maximal values as well as by the huge standard deviations. The results for ReSyst are again considerably higher. Several students seem to have worked intensely with the Learning Units, this will hopefully continue in the following years.

The units are now open in general and can be permanently accessed at:

`http://typo.service.tu-berlin.de/course/view.php?id=21`

As the Learning Units can work independently of university courses and university locations, the approach is highly reusable. For differences concerning definitions in-between courses, either the content can be adapted, or instructions on the differences can be added.

[1] The interactions of students in the studies are not part of this number as the studies were done using different copies of these courses.

Although this approach was developed for the area of theoretical computer science, it is easily usable for other disciplines. The principles the Learning Units are based on can easily be used not only for mathematics and physics but also for many further disciplines. As Moodle courses can be exported and imported on different Moodle platforms, the Learning Units can be easily embedded in other Learning Platforms, e.g. platforms directly connected to a university course. The Learning Units can be expanded in many forms, e.g. for programming courses that could use additional JUnit-Tests on Moodle to check programming solutions as more advanced exercises.

Hopefully, the Learning Units will be used in many courses on formal languages and automata and reactive systems, and the approach will be used and varied for different disciplines in the future.

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Appendix A

Digital Appendix

For further usage of the research data and questionnaires created for the research approach presented in this dissertation, the pre-processed data, the questionnaires, questionnaire results and plots can be found in the so-called digital appendix [Wil19] in depositOnce – the repository for research data and publications of Technische Universität Berlin at:
http://dx.doi.org/10.14279/depositonce-8976

Those files, bundled into a zip file, include the data as well as the outputs concerning normality of the data, significance testing and correlation results. The zip file always contains the files used in SPSS as well as non-proprietary versions (csv for data and pdf for outputs). The zip file further contains a more detailed explanation of the folder structure.

The following gives an overview of the elements contained:

Item	Key
AN386	ANOVA test results for the combined reduced FLAT studies and the reduced ReSyst Berlin study
CO837	Correlation results for all studies
MA629	Resulting categories and generalized answers for open questions from Mayring evaluation
MA772	Resulting categories and pre-processed interviews from Mayring evaluation
PR813	Preprocessed data of the studies (all studies as well as reduced to those analyzed in Chapter 6)

Item	Key
QU507	Exemplary questionnaires for FLAT and ReSyst
RE264	Data for repeaters

Appendix B

Further Survey Results

This chapter presents data analysis results of the surveys that are of interest, yet omitted from the main part of the dissertation for readability reasons.

B.1 Normal Distribution Berlin and Potsdam

This section will present the results on skewness, kurtosis and the results of the Kolmogorov-Smirnov test on non-normality for the main studies (*FLAT Berlin*, *FLAT Potsdam* and *ReSyst Berlin*), each reduced to those participants that filled out all three respective surveys. In the tables, values indicating deviations from normal distributions are shown in bold. In all these cases, the strong indication for non-normality led to the usage of the non-parametric Mann-Whitney U test for significance testing. Table B.1 presents the results on normality of the data concerning motivation for the *FLAT Berlin* and *FLAT Potsdam* studies. In all three surveys, considerable indications for skew can be found, e.g. for *anxiety* and *challenge* for group B in survey 1, and *anxiety* for both groups in survey 2 and 3. Values close to zero are desirable for this scale as well as for the scale on kurtosis. For the first survey, the indications for kurtosis are overall lower, but in some cases (e.g. *interest* for both groups) still far from zero. In survey 2, values above one can be found for *anxiety* in group A and *challenge* in group B and additionally in survey 3 for group A on *interest* and *challenge*. The Kolmogorov-Smirnov test is significant for $p < 0.05$, and several such cases can be found for all three surveys, e.g. for the *probability of success* scale in survey 1 for group A and *anxiety* for group B. The former significance value is high, whereas the latter is rather close to the border of non-significance. In surveys 2 and 3, e.g. the values on *anxiety* for group A are significant in both cases, as are the values on *probability of success* for group B. Overall, there are strong indications for non-normality in this data.

Table B.1: Values for skew, kurtosis and results of the Kolmogorov-Smirnov test for the motivation data for the *FLAT Berlin* and *FLAT Potsdam* studies, reduced to those participants that filled out all three surveys, for group A (n = 19) and group B (n = 21).

S.	Scale	Skewness (Gr.A / Gr.B)	Kurtosis (Gr.A / Gr.B)	Kolmogorov-Smirnov Results (Gr.A / Gr.B)
1	Interest	-0.24 / 0.20	-0.97 / -0.75	D(19), $p = 0.200$ / D(21), $p = 0.200$
	Prob.o.s.	-0.56 / -0.04	-0.52 / -0.31	**D(19),** $p = 0.002$ / D(21), $p = 0.134$
	Anxiety	0.79 / **1.32**	0.52 / 2.35	D(19), $p = 0.200$ / **D(21),** $p = 0.048$
	Challenge	0.05 / **-1.17**	-0.50 / 3.15	D(19), $p = 0.167$ / D(21), $p = 0.200$
2	Interest	**-1.20** / -0.68	0.68 / -0.51	**D(19),** $p = 0.000$ / D(21), $p = 0.200$
	Prob.o.s.	-0.17 / -0.21	-0.70 / 0.31	D(19), $p = 0.072$ / **D(21),** $p = 0.035$
	Anxiety	**1.48** / **1.16**	**1.74** / 0.92	**D(19),** $p = 0.011$ / D(21), $p = 0.055$
	Challenge	-0.44 / -0.78	-0.41 / **1.23**	D(19), $p = 0.200$ / D(21), $p = 0.173$
3	Interest	**-1.28** / -0.54	**2.37** / -0.879	D(19), $p = 0.093$ / D(21), $p = 0.200$
	Prob.o.s.	-0.062 / 0.074	-0.663 / 0.364	D(19), $p = 0.129$ / **D(21),** $p = 0.028$
	Anxiety	**1.04** / **1.00**	0.632 / 0.46	**D(19),** $p = 0.014$ / D(21), $p = 0.125$
	Challenge	-0.25 / -0.29	**-1.08** / -0.55	D(19), $p = 0.200$ / D(21), $p = 0.200$

Table B.2 presents the results on normality of the data concerning motivation for the *ReSyst Berlin* study. Many indications on skewness can be found here, especially in surveys 1 and 2, where group A in survey 1 and group B in survey 2 both have high values for three of their four scales. Especially the value on anxiety is high for group A for both surveys and for group B for the second survey. For survey 3, indications for skew can be found on the *interest* scale for group A and as well on the *probability of success* scale for group B. Indications for kurtosis can also be found for all three surveys, especially group B has high values on this scale for *probability of success* and *anxiety* in all three surveys. Only two significant results can be found for the Kolmogorov-Smirnov test: For *challenge* in group B in survey 1 and *interest* in group A in survey 3. Overall, there are again strong indications for non-normality in this data.

Table B.3 presents the results on normality of the data concerning competencies for the combined *FLAT Berlin* and *FLAT Potsdam* studies and for the *ReSyst Berlin* study. For the first studies, a high value can be found in one of the groups for one survey only, indicating kurtosis. In contrast to this, all results of the Kolmogorov-Smirnov test are significant, $p < 0.05$. This strongly indicates non-normality. For the *ReSyst Berlin* study, no strong indications on skewness, but indications on kurtosis can be found in all three surveys.The result of the Kolmogorov-Smirnov test for group B is significant in survey 3 only. Overall there are again strong indications for non-normality in this data.

Table B.2: Values for skew, kurtosis and results of the Kolmogorov-Smirnov test for the motivation data for the *ReSyst Berlin* study, reduced to those participants that filled out all three surveys, comparing group A (n = 9) and group B (n = 12).

S.	Scale	Skewness (Gr.A / Gr.B)	Kurtosis (Gr.A / Gr.B)	Kolmogorov-Smirnov Results (Gr.A / Gr.B)
1	Interest	**-1.00** / -0.35	0.20 / -0.44	D(9), $p = 0.056$ / D(12), $p = 0.200$
	Prob.o.s.	-0.55 / **-1.23**	-0.93 / **2.60**	D(9), $p = 0.200$ / D(12), $p = 0.200$
	Anxiety	**1.58** / -0.10	**2.72** / **-1.37**	D(9), $p = 0.200$ / D(12), $p = 0.200$
	Challenge	**-1.28** / -0.86	0.26 / -0.61	D(9), $p = 0.062$ / **D(12),** $p = 0.040$
2	Interest	**-1.11** / **1.21**	0.93 / 0.69	D(9), $p = 0.200$ / D(12), $p = 0.200$
	Prob.o.s.	-0.42 / **-1.05**	-0.83 / **1.80**	D(9), $p = 0.200$ / D(12), $p = 0.096$
	Anxiety	**1.61** / **2.85**	**2.85** / **-2.00**	D(9), $p = 0.128$ / D(12), $p = 0.169$
	Challenge	-0.15 / -0.86	-0.92 / 0.10	D(9), $p = 0.200$ / D(12), $p = 0.200$
3	Interest	**-1.04** / -0.13	-0.82 / -0.14	**D(9),** $p = 0.008$ / D(12), $p = 0.200$
	Prob.o.s.	0.47 / **2.30**	0.94 / **6.93**	D(9), $p = 0.200$ / D(12), $p = 0.200$
	Anxiety	0.89 / 0.22	0.79 / **-1.74**	D(9), $p = 0.200$ / D(12), $p = 0.060$
	Challenge	0.02 / -0.56	**-1.90** / -0.92	D(9), $p = 0.200$ / D(12), $p = 0.136$

Table B.3: Values for skew, kurtosis and results of the Kolmogorov-Smirnov test for the combined *FLAT Berlin* and *FLAT Potsdam* studies and the *ReSyst Berlin* study, reduced to those participants that filled out all three surveys.

S.	Location	Skewness (Gr.A / Gr.B)	Kurtosis (Gr.A / Gr.B)	Kolmogorov-Smirnov Results (Gr.A / Gr.B)
1	FLAT Berlin, FLAT Potsdam	-0.69 / 0.52	-0.04 / 0.01	**D(19),** $p = 0.000$ / **D(21),** $p = 0.001$
2		-0.41 / -0.27	**-1.21** / -0.87	**D(19),** $p = 0.001$ / **D(21),** $p = 0.048$
3		-0.69 / **-1.07**	-0.23 / 0.31	**D(19),** $p = 0.023$ / **D(21),** $p = 0.000$
1	ReSyst Berlin	-0.37 / 0.00	0.60 / **-1.27**	D(9), $p = 0.126$ / D(12), $p = 0.200$
2		-0.54 / -0.10	-0.15 / **-1.21**	D(9), $p = 0.200$ / D(12), $p = 0.200$
3		-0.50 / 0.48	**-1.28** / -0.87	D(9), $p = 0.059$ / **D(12),** $p = 0.028$

B.2 Studies in Duisburg-Essen, Aachen and Salzburg

This section presents the results for the three studies at Universität Duisburg-Essen, Universität Salzburg and RWTH Aachen that were omitted from the main survey analysis in Chapter 6. For the *FLAT Duisburg-Essen* study, the means and standard deviations on motivation can be found in Table B.4 and the results of the significance tests in Table B.5. For the *ReSyst Aachen* study, the means and standard deviations on motivation can be found in Table B.6. Significance tests are not reported for this study, due to the limited group sizes. For the *ReSyst Salzburg* studies, the means and standard deviations on motivation can be found in Table B.7. The results of the significance tests can be found in Table B.8.

On competencies, the means and standard deviations for the *FLAT Duisburg-Essen* study can be found in Table B.9 and the results of the significance tests in Table B.10. For the two *ReSyst*-studies, the means and standard deviations can be found in Table B.11, and the results of the significance tests in Table B.12.

As discussed in Section 6, all these results have to be considered cautiously, because participation was low in all three studies. Sampling variation therefore heavily influences the results. Additionally, the study in Duisburg-Essen gave rise to the assumption that the students did not fully understand the questions (almost all students answered the filtering question in survey 2 whether they had already had access to the Learning Unit wrong). Therefore, no further interpretation is given.

Table B.4: Mean and standard deviation (in brackets) of motivation in the *FLAT Duisburg-Essen* study.

Survey	Scale	n (Gr.A / Gr.B)	Group A	Group B
1	Interest	11 / 12	4.11 (1.01)	4.10 (0.74)
	Probability of success	11 / 12	3.61 (0.70)	4.08 (1.05)
	Anxiety	11 / 12	3.67 (1.35)	3.98 (1.06)
	Challenge	11 / 12	4.2 (0.97)	4.85 (1.07)
2	Interest	4 / 2	**4.80 (0.94)**	4.60 (0)
	Probability of success	4 / 2	**3.06 (0.38)**	4.63 (1.24)
	Anxiety	4 / 2	**2.70 (1.51)**	4.90 (0.71)
	Challenge	4 / 2	**4.13 (1.66)**	5.25 (0)
3	Interest	2 / 2	5.30 (0.42)	**3.60 (0.85)**
	Probability of success	2 / 2	4.25 (0.71)	**3.88 (0.18)**
	Anxiety	2 / 2	3.60 (1.98)	**3.60 (0.85)**
	Challenge	2 / 2	5.13 (1.59)	**4.75 (1.41)**

Table B.5: Sample size N, test-statistic U, standardized test-statistic z, significance value p (significant for $p < 0.005$) and effect size r for motivation in the *FLAT Duisburg-Essen* study.

Survey	Scale	N	U	z	p	r
1	Interest	23	67.50	0.093	0.928	0.02
	Prob.o.s.	23	81.50	0.964	0.347	0.20
	Anxiety	23	71.50	0.339	0.74	0.07
	Challenge	23	87.50	1.328	0.19	0.28
2	Interest	6	2.00	-0.953	0.533	-0.39
	Prob.o.s.	6	8.00	1.967	0.133	0.80
	Anxiety	6	7.00	1.389	0.267	0.57
	Challenge	6	6.00	0.939	0.533	0.38
3	Interest	4	0.00	-1.549	0.333	-0.77
	Prob.o.s.	4	1.50	-0.408	0.667	-0.20
	Anxiety	4	2.00	0	1	0.00
	Challenge	4	1.00	-0.775	0.667	-0.39

Table B.6: Mean and standard deviation (in brackets) of motivation in the *ReSyst Aachen* study.

Survey	Scale	n (Gr.A / Gr.B)	Group A	Group B
1	Interest	2 / 2	4.10 (0.14)	3.30 (1.56)
	Probability of success	2 / 2	4.50 (0.71)	4.25 (1.06)
	Anxiety	2 / 2	3.40 (0.85)	1.80 (1.13)
	Challenge	2 / 2	4.13 (0.18)	3.00 (0.00)
2	Interest	1 / 1	5.00	**5.20**
	Probability of success	1 / 1	4.50	**4.25**
	Anxiety	1 / 1	2.20	**4.20**
	Challenge	1 / 1	5.00	**6.00**
3	Interest	2 / 1	**3.50 (1.84)**	3.60
	Probability of success	2 / 1	**4.38 (0.18)**	5.00
	Anxiety	2 / 1	**3.20 (2.55)**	6.20
	Challenge	2 / 1	**3.63 (1.24)**	3.00

Table B.7: Mean and standard deviation (in brackets) of motivation in the *ReSyst Salzburg* study.

Survey	Scale	n (Gr.A / Gr.B)	Group A	Group B
1	Interest	5 / 4	4.80 (0.60)	4.20 (0.23)
	Probability of success	5 / 4	3.35 (0.63)	3.63 (0.66)
	Anxiety	5 / 4	4.00 (1.26)	3.05 (1.05)
	Challenge	5 / 4	4.30 (1.50)	4.81 (0.69)
2	Interest	5 / 2	**4.64 (1.12)**	3.90 (0.71)
	Probability of success	5 / 2	**3.45 (0.62)**	3.88 (1.59)
	Anxiety	5 / 2	**3.00 (1.44)**	3.90 (0.42)
	Challenge	5 / 2	**3.25 (1.20)**	4.63 (0.53)
3	Interest	3 / 2	4.07 (1.30)	**4.20 (0.85)**
	Probability of success	3 / 2	3.67 (0.38)	**4.13 (0.18)**
	Anxiety	3 / 2	1.93 (1.14)	**3.80 (1.41)**
	Challenge	3 / 2	4.25 (1.09)	**4.38 (0.18)**

Table B.8: Sample size N, test-statistic U, standardized test-statistic z, significance value p (significant for $p < 0.005$) and effect size r for motivation in the *ReSyst Salzburg* study.

Survey	Scale	N	U	z	p	r
1	Interest	9	4.00	-1.495	0.190	-0.50
	Prob.o.s.	9	13.00	0.744	0.556	0.25
	Anxiety	9	6.50	-0.865	0.413	-0.29
	Challenge	9	10.50	0.123	1.000	0.04
2	Interest	7	2.50	-0.977	0.381	-0.37
	Prob.o.s.	7	6.00	0.391	1.000	0.15
	Anxiety	7	7.00	0.775	0.571	0.29
	Challenge	7	8.50	1.380	0.190	0.52
3	Interest	5	3.00	0.000	1.000	0.00
	Prob.o.s.	5	5.50	1.48	0.200	0.66
	Anxiety	5	5.00	1.155	0.400	0.52
	Challenge	5	2.00	-0.577	0.800	-0.26

Table B.9: Mean and standard deviation (in brackets) of competencies in the *FLAT Duisburg-Essen* study.

Survey	Location	n (Gr.A / Gr.B)	Group A	Group B
1	**FLAT Duisburg-Essen**	11 / 12	0.52 (0.31)	0.43 (0.22)
2		4 / 2	**0.63 (0.44)**	0.17 (0.24)
3		2 / 2	0.25 (0.35)	**0.19 (0.27)**

Table B.10: Sample size N, test-statistic U, standardized test-statistic z, significance value p (significant for $p < 0.005$) and effect size r for competencies in the *FLAT Duisburg-Essen* study.

Survey	Location	N	U	z	p	r
1	**FLAT Duisburg-Essen**	23	52.50	-0.858	0.413	-0.18
2		6	1.50	-1.174	0.267	-0.48
3		4	1.50	-0.408	0.667	-0.20

Table B.11: Mean and standard deviation (in brackets) of competencies in the *ReSyst* studies.

Survey	Location	n (Gr.A / Gr.B)	Group A	Group B
1	**ReSyst Aachen**	2 / 2	0.90 (0.14)	0.50 (0.14)
2		1 / 1	0.80	**0.80**
3		2 / 1	**0.50 (0.00)**	0.67
1	**ReSyst Salzburg**	5 / 4	0.80 (0.28)	0.65 (0.10)
2		5 / 2	**0.63 (0.22)**	0.75 (0.12)
3		3 / 2	0.67 (0.23)	**0.70 (0.14)**

Table B.12: Sample size N, test-statistic U, standardized test-statistic z, significance value p (significant for $p < 0.005$) and effect size r for competencies in the *ReSyst* studies.

Survey	Location	N	U	z	p	r
1	**ReSyst Aachen**	4	0.00	-1.549	0.333	-0.77
2		2	0.50	0.000	1.000	0.00
3		3	2.00	1.414	1.000	0.82
1	**ReSyst Salzburg**	9	6.50	-0.912	0.413	-0.30
2		7	6.50	0.609	0.571	0.23
3		5	3.00	0.000	1.000	0.00

B.3 QCM – Repeaters

We assume repeaters, students that had heard the respective course before, to be of a slightly different population than the regular course participants. Therefore, their values are tested separately and presented in this section. Short interpretations will be given, but it is important to note that the number of participants that are repeaters is small, and therefore, a lot of sampling variation can be found in this data.

(*FLAT Berlin*) The group of repeaters in the *FLAT Berlin* study initially contained eight students, split up into group A (n = 4) and group B (n = 4). In surveys 2 and 3, only three students in group A and none in group B participated further. Therefore no significance tests were possible on the data of the surveys 2 and 3, and SPSS also did not perform the Kolmogorov-Smirnov tests on the groups, due to the small sample sizes. Table B.13 shows the values for the students that had already heard the course at least once before. Comparisons are not possible, as no students of group B answered the surveys two and three. Therefore, only the values for group A will be interpreted here. Contrary to the first-time study participants, the *interest* for repeaters stayed almost constant between surveys 1 and 2 and decreased strongly between surveys 2 and 3. For the non-repeaters, the value increased and then decreased slightly for group A and considerably for group B. The general level of *interest* is lower for the repeaters. The *probability of success* of the repeaters was also generally higher than for non-repeaters and, contrary to the non-repeaters, decreased first and increased later. As there are so few students in group A and none in group B, these values can hardly be interpreted concerning their progress. The values for *anxiety* and *challenge* vary in between the surveys in a similar way for repeaters and non-repeaters, although the values for repeaters have a generally higher mean. This could be an effect of those students having already heard the content. Interestingly, the values for *anxiety* are also generally higher for the repeaters. A possible explanation is that the students had already failed the course once or dropped-out, increasing their anxiety. The level of *anxiety* could also be generally higher for students further in their degree programs. The values for *challenge* also have a constantly higher mean, possibly because the perceived challenge after having heard the course already is higher for these students.

As there are no significance tests possible for surveys 2 and 3, the results on normal distribution, kurtosis and skew will not be presented here but can be found in the digital Appendix (Appendix A-RE264). As there was evidence for non-normality, the mean differences for group A as well as for group B in survey 1 were tested using again the

Mann-Whitney-U test. None of the means differed significantly (the significance value was never less than 0.005).

Table B.13: Mean and standard deviation (in brackets) of motivation for repeaters in the *FLAT Berlin* study.

Survey	Scale	n (Gr.A / Gr.B)	Group A	Group B
1	Interest	4 / 4	3.65 (1.40)	2.90 (0.70)
	Probability of success	4 / 4	4.38 (0.72)	4.13 (1.03)
	Anxiety	4 / 4	4.45 (1.83)	3.75 (2.04)
	Challenge	4 / 4	4.75 (1.34)	4.44 (1.43)
2	Interest	3 / 0	**3.67 (0.12)**	-
	Probability of success	3 / 0	**4.17 (0.63)**	-
	Anxiety	3 / 0	**4.20 (1.11)**	-
	Challenge	3 / 0	**4.17 (0.29)**	-
3	Interest	3 / 0	3.00 (0.35)	-
	Probability of success	3 / 0	4.25 (0.25)	-
	Anxiety	3 / 0	4.00 (0.87)	-
	Challenge	3 / 0	4.08 (0.14)	-

(*FLAT Duisburg-Essen*) The group of repeaters in the *FLAT Duisburg-Essen* study (Table B.14) started with three students in group A and three students in group B. The values for the QCM scales were fairly similar. None of the students in group A filled out the successive surveys, two students of group B filled out survey 2 and only one student filled out survey 3. These low values need to be considered in this context. The *interest* value first decreased for group B in survey 2 and then increased again in survey 3, in contrast to the values for group B of non-repeaters, where they first increased and then decreased again. The changes in *probability of success* and *anxiety* were similar to those in the group B of non-repeaters. The value for *challenge* first decreased, then increased, while the value for group B of non-repeaters in the study did the opposite. A possible interpretation might be that the content in-between surveys 1 and 2 was less complicated, as they had heard it before. Interestingly, this possible interpretation is, however, in contrast to the result for repeaters in the *FLAT Berlin* study. Another possible interpretation is that these results are caused by sampling variation without an underlying effect.

As there are no significance tests possible for surveys 2 and 3, the results on normal distribution, kurtosis and skew will not be presented here but can be found in the digital Appendix (Appendix A-RE264). As there was evidence for non-normality, the mean differences for group A and group B in survey 1 were tested using a Mann-Whitney-U test. None of the means differed significantly (significance value was never less than 0.005).

Table B.14: Mean and standard deviation (in brackets, if computable) of motivation for repeaters in the *FLAT Duisburg-Essen* study.

Survey	Scale	n (Gr.A / Gr.B)	Group A	Group B
1	Interest	3 / 3	4.07 (1.45)	3.67 (0.95)
	Probability of success	3 / 3	3.92 (0.76)	3.67 (0.52)
	Anxiety	3 / 3	3.47 (1.21)	3.33 (1.68)
	Challenge	3 / 3	4.5 (1.00)	4.08 (0.72)
2	Interest	0 / 2	-	2.40 (0.28)
	Probability of success	0 / 2	-	4.5 (1.41)
	Anxiety	0 / 2	-	3.80 (1.98)
	Challenge	0 / 2	-	3.63 (0.18)
3	Interest	0 / 1	-	**4.20**
	Probability of success	0 / 1	-	**3.25**
	Anxiety	0 / 1	-	**3.40**
	Challenge	0 / 1	-	**4.50**

(*FLAT Potsdam*) The first survey in the *FLAT Potsdam* study was filled out by ten repeaters. The values can be found in Table B.15. As group B decreased to one student in survey 2 and to no students in survey 3, the short analysis will concentrate on group A. The values for *interest* and *challenge* changed similar to those of the non-repeaters in the study. Interestingly, as for the *FLAT Berlin* repeaters before, the *probability of success* of the repeaters decreased first and increased later. This is contrary to the values for non-repeaters. The perceived challenge was generally higher in the group of repeaters. The value for *anxiety* was considerably higher in the repeaters group throughout all three surveys, and while it decreased first and then increased again slightly for group A of non-repeaters, it changed in the opposite direction among the repeaters group. The *anxiety* in the group of repeaters seemed to be higher, possibly because of a different awareness of the content complexity.

Due to the small group sizes, the Kolmogorov-Smirnov test was not possible at all for group B, and for group A in survey 3, tests for kurtosis and skewness could also only be carried out for a part of the results. There still was a strong indication for skewness and kurtosis in the results. The Kolmogorov-Smirnov test was not significant, $p < 0.05$, for group A in the first two surveys. Test results are not presented here but can be found in the digital Appendix (Appendix A-RE264).

Table B.16 shows the values for the Mann-Whitney U test on the surveys 1 and 2. In the group of repeaters, there were no participants of group B that filled out survey 3. Therefore no significance tests were possible. No significant values, $p < 0.005$, were found. The larger effect sizes for survey 2 are due to the small number of participants and therefore not of interest.

Overall, no clear patterns for repeaters differing them from non-repeaters could be found, possibly due to the small number of repeaters in the studies. In two cases, the levels of *anxiety* were unusually high for repeaters. This could be simply due to sampling variation. Such a high level of anxiety might also be specific to repeaters. This is worth being pursued in the future.

Table B.15: Mean and standard deviation (in brackets) of motivation for repeaters in the *FLAT Potsdam* study.

Survey	Scale	n (Gr.A / Gr.B)	Group A	Group B
1	Interest	7 / 3	4.31 (1.64)	3.73 (0.12)
	Probability of success	7 / 3	4.07 (0.85)	3.75 (0.43)
	Anxiety	7 / 3	4.14 (1.96)	4.07 (0.81)
	Challenge	7 / 3	4.79 (1.5)	4.67 (0.95)
2	Interest	5 / 1	**4.72 (1.32)**	2.40
	Probability of success	5 / 1	**3.85 (0.45)**	4.5
	Anxiety	5 / 1	**4.44 (0.98)**	5.00
	Challenge	5 / 1	**5.85 (0.68)**	4.00
3	Interest	3 / 0	4.20 (1.64)	-
	Probability of success	3 / 0	3.92 (0.63)	-
	Anxiety	3 / 0	3.13 (1.92)	-
	Challenge	3 / 0	5.58 (0.52)	-

Table B.16: Sample size N, test-statistic U, standardized test-statistic z, significance value p (significant for $p < 0.005$) and effect size r for motivation of repeaters in the *FLAT Potsdam* study.

Survey	Scale	N	U	z	p	r
1	Interest	10	9.00	-0.343	0.833	-0.11
	Prob.o.s.	10	8.00	-0.584	0.667	-0.18
	Anxiety	10	12.00	0.343	0.833	0.11
	Challenge	10	10.50	0.000	1.000	0.00
2	Interest	6	0.00	-1.464	0.333	-0.60
	Prob.o.s.	6	4.50	1.206	0.333	0.49
	Anxiety	6	4.00	0.981	0.667	0.40
	Challenge	6	0.00	-1.464	0.333	-0.60

B.4 Competencies – Repeaters

As only a few repeaters participated in the studies and even fewer answered all three surveys, significance tests were omitted from this part of the analysis. Table B.17 shows the values for repeaters in four of the studies. For the *ReSyst Berlin* study surveys 2 and 3 were omitted, as no repeaters answered them. The studies in Aachen and Salzburg are not part of the analysis, as no repeaters participated in the study there.

The results showed overall similar starting levels of competency as for non-repeaters. For the *FLAT Berlin* study, the values for group A stayed the same. None of the repeaters in group B answered the subsequent surveys, so no further comparisons were possible. For the *FLAT Duisburg-Essen* study, the groups of repeaters also started on similar levels. Group A stopped participating after the first survey and for group B, the value first increased, then decreased strongly for survey 3. The *FLAT Potsdam* study was the only study where a comparison was possible between surveys 1 and 2. Here, the value for group A increased more strongly than the value for group B. Possibly, the Learning Unit increased the competencies for group A further. For the *ReSyst Berlin* study, the groups started did not start well balanced, but as none of the repeaters answered further surveys, comparisons were not possible. Overall, no clear tendency how the usage of the Learning Unit affects the acquired competencies can be detected from this data.

Table B.17: Mean and standard deviation (in brackets) of competencies for repeaters in the studies.

Survey	Location	n (Gr.A / Gr.B)	Group A	Group B
1	**FLAT Berlin**	4 / 4	0.50 (0.42)	0.55 (0.19)
2		3 / 0	**0.50 (0.33)**	-
3		3 / 0	0.50 (0.33)	-
1	**FLAT Duisburg-Essen**	3 / 3	0.53 (0.23)	0.47 (0.23)
2		0 / 2	-	0.67 (0.47)
3		0 / 1	-	**0.13**
1	**FLAT Potsdam**	7 / 3	0.43 (0.14)	0.33 (0.31)
2		5 / 1	**0.63 (0.30)**	0.50
3		3 / 0	0.33 (0.38)	-
1	**ReSyst Berlin**	1 / 2	0.2	0.4 (0.28)

B.5 Correlation Coefficients

This part of the appendix contains tables with the correlation coefficients and significance values for several variables for the four largest studies. Suggestive values ($0.005 < p < 0.05$) are marked yellow, significant values ($p < 0.005$) are marked green. The correlation values for the other studies and for repeaters can be found in the digital Appendix (Appendix A-RE264).

The tables for *FLAT Berlin* survey 1 (n = 74, except for age with n = 73):

B.18 (part 1) and B.19 (part 2).

The tables for *FLAT Berlin* survey 2 (n = 45, except for age with n = 44):

B.20 (part 1) and B.21 (part 2).

The tables for *FLAT Berlin* survey 3 (n = 36):

B.22 (part 1) and B.23 (part 2).

The tables for *FLAT Duisburg-Essen* survey 1 (n = 23):

B.24 (part 1) and B.25 (part 2).

The tables for *FLAT Duisburg-Essen* survey 2 (n = 6, except for Learning alone or in groups with n = 5):

B.26 (part 1) and B.27 (part 2).

The tables for *FLAT Duisburg-Essen* survey 3 (n = 4):

B.28 (part 1) and B.29 (part 2).

The tables for *FLAT Potsdam* survey 1 (n = 28):

B.30 (part 1) and B.31 (part 2).

The tables for *FLAT Potsdam* survey 2 (n = 14):

B.32 (part 1) and B.33 (part 2).

The tables for *FLAT Potsdam* survey 3 (n = 9):

B.34 (part 1) and B.35 (part 2).

The tables for *ReSyst Berlin* survey 1 (n = 53):

B.36 (part 1) and B.37 (part 2).

The tables for *ReSyst Berlin* survey 2 (n = 29):

B.38 (part 1) and B.39 (part 2).

The tables for *ReSyst Berlin* survey 3 (n = 26):

B.40 (part 1) and B.41 (part 2).

Correlation for visual/verbal learning style and preferences for text or video usage in the studies *FLAT Berlin*, *FLAT Potsdam* and *ReSyst Berlin*: B.42.

Due to the small number of participants in each group, the correlation coefficients for the other studies were not computed.

The following abbreviations will be used in the tables:

- Active and reflective learners: ACT/REF
- Sensing and intuitive learners: SEN/INT
- Visual and verbal learners: VIS/VRB
- Sequential and global learners: SEQ/GLO

Table B.18: Correlation coefficient and significance value (significant for $p < 0.005$) of Kendall's τ for the first *FLAT Berlin* survey (part 1).

FLAT Berlin 1	QCM Interest	QCM Probability of success	QCM Anxiety	QCM Challenge
Age	$\tau =$ 0.051, $p = 0.544$	$\tau =$ 0.100, $p = 0.249$	$\tau =$ -0.079, $p = 0.353$	$\tau =$ 0.002, $p = 0.981$
Sex	$\tau =$ 0.216, $p = 0.026$	$\tau =$ 0.124, $p = 0.217$	$\tau =$ 0.002, $p = 0.985$	$\tau =$ -0.54, $p = 0.584$
Work or entertainment	$\tau =$ -0.117, $p = 0.153$	$\tau =$ 0.180, $p = 0.032$	$\tau =$ 0.013, $p = 0.877$	$\tau =$ -0.060, $p = 0.465$
Self-regulated learning	$\tau =$ 0.208, $p = 0.010$	$\tau =$ -0.057, $p = 0.492$	$\tau =$ -0.206, $p = 0.011$	$\tau =$ 0.037, $p = 0.646$
Computer affinity	$\tau =$ -0.040, $p = 0.623$	$\tau =$ -0.083, $p = 0.316$	$\tau =$ 0.031, $p = 0.701$	$\tau =$ -0.024, $p = 0.772$
Self-assessment A	$\tau =$ 0.182, $p = 0.033$	$\tau =$ 0.028, $p = 0.747$	$\tau =$ -0.047, $p = 0.586$	$\tau =$ 0.067, $p = 0.436$
Self-assessment B	$\tau =$ 0.089, $p = 0.311$	$\tau =$ 0.096, $p = 0.288$	$\tau =$ -0.030, $p = 0.730$	$\tau =$ 0.020, $p = 0.817$
Learning alone or in groups	$\tau =$ 0.075, $p = 0.434$	$\tau =$ 0.117, $p = 0.236$	$\tau =$ 0.071, $p = 0.457$	$\tau =$ -0.034, $p = 0.722$
ACT/REF	$\tau =$ 0.146, $p = 0.088$	$\tau =$ -0.044, $p = 0.616$	$\tau =$ 0.131, $p = 0.128$	$\tau =$ 0.012, $p = 0.887$
SEN/INT	$\tau =$ 0.084, $p = 0.319$	$\tau =$ 0.077, $p = 0.377$	$\tau =$ -0.010, $p = 0.906$	$\tau =$ -0.182, $p = 0.033$
VIS/VRB	$\tau =$ 0.090, $p = 0.295$	$\tau =$ 0.016, $p = 0.853$	$\tau =$ 0.080, $p = 0.351$	$\tau =$ 0.021, $p = 0.809$
SEQ/GLO	$\tau =$ -0.030, $p = 0.726$	$\tau =$ 0.116, $p = 0.186$	$\tau =$ 0.131, $p = 0.126$	$\tau =$ -0.140, $p = 0.103$

Table B.19: Correlation coefficient and significance value (significant for $p < 0.005$) of Kendall's τ for the first *FLAT Berlin* survey (part 2).

FLAT Berlin 1	Competencies A	Competencies B	Competencies Content
Age	$\tau =$ -0.247, $p = 0.012$	$\tau =$ -0.191, $p = 0.055$	$\tau =$ -0.012, $p = 0.898$
Sex	$\tau =$ 0.130, $p = 0.249$	$\tau =$ 0.092, $p = 0.421$	$\tau =$ 0.184, $p = 0.077$
Work or entertainment	$\tau =$ 0.032, $p = 0.733$	$\tau =$ -0.022, $p = 0.823$	$\tau =$ 0.047, $p = 0.594$
Self-regulated learning	$\tau =$ 0.075, $p = 0.426$	$\tau =$ -0.019, $p = 0.843$	$\tau =$ 0.121, $p = 0.161$
Computer affinity	$\tau =$ 0.043, $p = 0.649$	$\tau =$ 0.127, $p = 0.182$	$\tau =$ 0.069, $p = 0.426$
Self-assessment A	$\tau =$ 0.407, $p = 0.000$	$\tau =$ 0.343, $p = 0.001$	$\tau =$ 0.109, $p = 0.232$
Self-assessment B	$\tau =$ 0.192, $p = 0.060$	$\tau =$ 0.200, $p = 0.053$	$\tau =$ 0.041, $p = 0.666$
Learning alone or in groups	$\tau =$ 0.242, $p = 0.030$	$\tau =$ 0.129, $p = 0.254$	$\tau =$ -0.082, $p = 0.422$
ACT/REF	$\tau =$ -0.009, $p = 0.925$	$\tau =$ -0.019, $p = 0.851$	$\tau =$ 0.138, $p = 0.133$
SEN/INT	$\tau =$ 0.268, $p = 0.006$	$\tau =$ 0.221, $p = 0.026$	$\tau =$ 0.056, $p = 0.536$
VIS/VRB	$\tau =$ 0.173, $p = 0.083$	$\tau =$ 0.115, $p = 0.255$	$\tau =$ 0.009, $p = 0.923$
SEQ/GLO	$\tau =$ 0.116, $p = 0.240$	$\tau =$ 0.075, $p = 0.456$	$\tau =$ 0.040, $p = 0.658$
QCM - Interest	$\tau =$ 0.291, $p = 0.002$	$\tau =$ 0.122, $p = 0.207$	$\tau =$ 0.196, $p = 0.026$
QCM - Probability of success	$\tau =$ 0.060, $p = 0.538$	$\tau =$ 0.110, $p = 0.268$	$\tau =$ -0.147, $p = 0.102$
QCM - Anxiety	$\tau =$ -0.158, $p = 0.097$	$\tau =$ -0.046, $p = 0.636$	$\tau =$ -0.089, $p = 0.311$
QCM - Challenge	$\tau =$ -0.135, $p = 0.160$	$\tau =$ -0.082, $p = 0.398$	$\tau =$ -0.077, $p = 0.384$

Table B.20: Correlation coefficient and significance value (significant for $p < 0.005$) of Kendall's τ for the second *FLAT Berlin* survey (part 1).

FLAT Berlin 2	QCM Interest	QCM Probability of success	QCM Anxiety	QCM Challenge
Age	$\tau =$ 0.033, $p = 0.766$	$\tau =$ 0.097, $p = 0.400$	$\tau =$ -0.080, $p = 0.473$	$\tau =$ 0.088, $p = 0.429$
Sex	$\tau =$ 0.159, $p = 0.207$	$\tau =$ -0.014, $p = 0.913$	$\tau =$ 0.080, $p = 0.525$	$\tau =$ -0.104, $p = 0.414$
Work or entertainment	$\tau =$ -0.098, $p = 0.360$	$\tau =$ -0.029, $p = 0.795$	$\tau =$ -0.006, $p = 0.953$	$\tau =$ 0.040, $p = 0.708$
Self-regulated learning	$\tau =$ 0.151, $p = 0.152$	$\tau =$ -0.086, $p = 0.431$	$\tau =$ -0.098, $p = 0.351$	$\tau =$ -0.072, $p = 0.498$
Computer affinity	$\tau =$ 0.042, $p = 0.695$	$\tau =$ -0.033, $p = 0.765$	$\tau =$ -0.096, $p = 0.361$	$\tau =$ 0.094, $p = 0.376$
Self-assessment A	$\tau =$ 0.411, $p = 0.000$	$\tau =$ -0.092, $p = 0.402$	$\tau =$ -0.285, $p = 0.007$	$\tau =$ 0.056, $p = 0.602$
Self-assessment B	$\tau =$ 0.172, $p = 0.111$	$\tau =$ -0.285, $p = 0.011$	$\tau =$ -0.016, $p = 0.882$	$\tau =$ -0.219, $p = 0.044$
Learning alone or in groups	$\tau =$ 0.065, $p = 0.605$	$\tau =$ -0.157, $p = 0.229$	$\tau =$ -0.263, $p = 0.035$	$\tau =$ 0.021, $p = 0.867$
ACT/REF	$\tau =$ 0.021, $p = 0.850$	$\tau =$ -0.007, $p = 0.952$	$\tau =$ 0.214, $p = 0.055$	$\tau =$ -0.027, $p = 0.811$
SEN/INT	$\tau =$ 0.053, $p = 0.634$	$\tau =$ -0.160, $p = 0.164$	$\tau =$ 0.132, $p = 0.230$	$\tau =$ 0.015, $p = 0.889$
VIS/VRB	$\tau =$ 0.061, $p = 0.583$	$\tau =$ 0.070, $p = 0.550$	$\tau =$ 0.097, $p = 0.386$	$\tau =$ -0.125, $p = 0.268$
SEQ/GLO	$\tau =$ 0.129, $p = 0.250$	$\tau =$ 0.072, $p = 0.535$	$\tau =$ -0.054, $p = 0.631$	$\tau =$ 0.109, $p = 0.331$

Table B.21: Correlation coefficient and significance value (significant for $p < 0.005$) of Kendall's τ for the second *FLAT Berlin* survey (part 2).

FLAT Berlin 2	Competencies A	Competencies B	Competencies Content
Age	$\tau =$ -0.025, $p = 0.843$	$\tau =$ 0.045, $p = 0.716$	$\tau =$ -0.101, $p = 0.392$
Sex	$\tau =$ 0.284, $p = 0.045$	$\tau =$ 0.047, $p = 0.741$	$\tau =$ 0.091, $p = 0.497$
Work or entertainment	$\tau =$ 0.108, $p = 0.368$	$\tau =$ 0.199, $p = 0.097$	$\tau =$ 0.110, $p = 0.335$
Self-regulated learning	$\tau =$ 0.105, $p = 0.375$	$\tau =$ -0.042, $p = 0.721$	$\tau =$ -0.027, $p = 0.808$
Computer affinity	$\tau =$ -0.093, $p = 0.434$	$\tau =$ 0.048, $p = 0.689$	$\tau =$ 0.079, $p = 0.485$
Self-assessment A	$\tau =$ 0.154, $p = 0.194$	$\tau =$ 0.148, $p = 0.213$	$\tau =$ 0.338, $p = 0.003$
Self-assessment B	$\tau =$ 0.232, $p = 0.055$	$\tau =$ 0.289, $p = 0.017$	$\tau =$ 0.136, $p = 0.237$
Learning alone or in groups	$\tau =$ -0.197, $p = 0.162$	$\tau =$ 0.005, $p = 0.971$	$\tau =$ -0.156, $p = 0.243$
ACT/REF	$\tau =$ 0.102, $p = 0.416$	$\tau =$ -0.160, $p = 0.203$	$\tau =$ 0.172, $p = 0.148$
SEN/INT	$\tau =$ 0.107, $p = 0.388$	$\tau =$ 0.280, $p = 0.024$	$\tau =$ 0.155, $p = 0.187$
VIS/VRB	$\tau =$ 0.124, $p = 0.324$	$\tau =$ -0.018, $p = 0.886$	$\tau =$ 0.099, $p = 0.405$
SEQ/GLO	$\tau =$ -0.288, $p = 0.021$	$\tau =$ 0.053, $p = 0.675$	$\tau =$ -0.110, $p = 0.354$
QCM - Interest	$\tau =$ 0.217, $p = 0.072$	$\tau =$ 0.063, $p = 0.602$	$\tau =$ 0.256, $p = 0.026$
QCM - Probability of success	$\tau =$ -0.115, $p = 0.361$	$\tau =$ -0.144, $p = 0.252$	$\tau =$ -0.109, $p = 0.359$
QCM - Anxiety	$\tau =$ 0.003, $p = 0.983$	$\tau =$ 0.016, $p = 0.896$	$\tau =$ -0.136, $p = 0.235$
QCM - Challenge	$\tau =$ 0.090, $p = 0.458$	$\tau =$ -0.008, $p = 0.948$	$\tau =$ 0.043, $p = 0.707$

Table B.22: Correlation coefficient and significance value (significant for $p < 0.005$) of Kendall's τ for the third *FLAT Berlin* survey (part 1).

FLAT Berlin 3	QCM Interest	QCM Probability of success	QCM Anxiety	QCM Challenge
Age	$\tau =$ 0.115, $p = 0.354$	$\tau =$ -0.079, $p = 0.544$	$\tau =$ -0.182, $p = 0.142$	$\tau =$ 0.012, $p = 0.923$
Sex	$\tau =$ 0.142, $p = 0.321$	$\tau =$ -0.208, $p = 0.166$	$\tau =$ 0.109, $p = 0.446$	$\tau =$ -0.056, $p = 0.696$
Work or entertainment	$\tau =$ -0.072, $p = 0.555$	$\tau =$ 0.028, $p = 0.823$	$\tau =$ 0.175, $p = 0.149$	$\tau =$ 0.120, $p = 0.322$
Self-regulated learning	$\tau =$ 0.215, $p = 0.071$	$\tau =$ 0.021, $p = 0.867$	$\tau =$ -0.142, $p = 0.234$	$\tau =$ 0.034, $p = 0.774$
Computer affinity	$\tau =$ -0.033, $p = 0.784$	$\tau =$ -0.192, $p = 0.125$	$\tau =$ 0.048, $p = 0.691$	$\tau =$ -0.097, $p = 0.419$
Self-assessment A	$\tau =$ 0.326, $p = 0.006$	$\tau =$ -0.098, $p = 0.435$	$\tau =$ -0.201, $p = 0.092$	$\tau =$ -0.008, $p = 0.945$
Self-assessment B	$\tau =$ 0.430, $p = 0.000$	$\tau =$ 0.035, $p = 0.781$	$\tau =$ -0.080, $p = 0.503$	$\tau =$ -0.044, $p = 0.712$
Learning alone or in groups	$\tau =$ 0.222, $p = 0.115$	$\tau =$ 0.409, $p = 0.006$	$\tau =$ -0.210, $p = 0.137$	$\tau =$ 0.139, $p = 0.325$
ACT/REF	$\tau =$ 0.085, $p = 0.504$	$\tau =$ -0.234, $p = 0.078$	$\tau =$ 0.241, $p = 0.058$	$\tau =$ -0.025, $p = 0.845$
SEN/INT	$\tau =$ 0.191, $p = 0.127$	$\tau =$ 0.184, $p = 0.162$	$\tau =$ 0.035, $p = 0.781$	$\tau =$ 0.012, $p = 0.923$
VIS/VRB	$\tau =$ 0.127, $p = 0.316$	$\tau =$ 0.126, $p = 0.342$	$\tau =$ 0.011, $p = 0.933$	$\tau =$ -0.028, $p = 0.824$
SEQ/GLO	$\tau =$ -0.035, $p = 0.781$	$\tau =$ 0.130, $p = 0.322$	$\tau =$ 0.086, $p = 0.496$	$\tau =$ 0.119, $p = 0.344$

Table B.23: Correlation coefficient and significance value (significant for $p < 0.005$) of Kendall's τ for the third *FLAT Berlin* survey (part 2).

FLAT Berlin 3	Competencies A	Competencies B	Competencies Content
Age	$\tau =$ -0.112, $p = 0.418$	$\tau =$ -0.028, $p = 0.845$	$\tau =$ -0.113, $p = 0.400$
Sex	$\tau =$ 0.368, $p = 0.021$	$\tau =$ 0.180, $p = 0.271$	$\tau =$ 0.310, $p = 0.046$
Work or entertainment	$\tau =$ 0.065, $p = 0.632$	$\tau =$ 0.209, $p = 0.129$	$\tau =$ 0.232, $p = 0.076$
Self-regulated learning	$\tau =$ 0.135, $p = 0.309$	$\tau =$ 0.187, $p = 0.166$	$\tau =$ 0.154, $p = 0.232$
Computer affinity	$\tau =$ 0.014, $p = 0.914$	$\tau =$ 0.118, $p = 0.384$	$\tau =$ -0.038, $p = 0.770$
Self-assessment A	$\tau =$ 0.145, $p = 0.274$	$\tau =$ 0.212, $p = 0.118$	$\tau =$ 0.156, $p = 0.226$
Self-assessment B	$\tau =$ 0.126, $p = 0.340$	$\tau =$ 0.240, $p = 0.076$	$\tau =$ 0.287, $p = 0.026$
Learning alone or in groups	$\tau =$ -0.032, $p = 0.837$	$\tau =$ 0.129, $p = 0.421$	$\tau =$ 0.056, $p = 0.715$
ACT/REF	$\tau =$ 0.144, $p = 0.308$	$\tau =$ -0.035, $p = 0.806$	$\tau =$ -0.120, $p = 0.381$
SEN/INT	$\tau =$ 0.126, $p = 0.365$	$\tau =$ 0.186, $p = 0.192$	$\tau =$ 0.110, $p = 0.416$
VIS/VRB	$\tau =$ 0.232, $p = 0.100$	$\tau =$ 0.160, $p = 0.266$	$\tau =$ 0.112, $p = 0.415$
SEQ/GLO	$\tau =$ -0.072, $p = 0.606$	$\tau =$ 0.002, $p = 0.987$	$\tau =$ -0.030, $p = 0.824$
QCM - Interest	$\tau =$ 0.202, $p = 0.134$	$\tau =$ 0.167, $p = 0.226$	$\tau =$ 0.225, $p = 0.087$
QCM - Probability of success	$\tau =$ -0.243, $p = 0.087$	$\tau =$ 0.017, $p = 0.908$	$\tau =$ 0.008, $p = 0.953$
QCM - Anxiety	$\tau =$ 0.253, $p = 0.062$	$\tau =$ -0.020, $p = 0.884$	$\tau =$ 0.146, $p = 0.266$
QCM - Challenge	$\tau =$ 0.073, $p = 0.588$	$\tau =$ -0.054, $p = 0.698$	$\tau =$ 0.227, $p = 0.084$

Table B.24: Correlation coefficient and significance value (significant for $p < 0.005$) of Kendall's τ for the first *FLAT Duisburg-Essen* survey (part 1).

FLAT DUE 1	QCM Interest	QCM Probability of success	QCM Anxiety	QCM Challenge
Age	$\tau =$ 0.470, $p =$ 0.003	$\tau =$ -0.092, $p =$ 0.568	$\tau =$ -0.141, $p =$ 0.374	$\tau =$ 0.056, $p =$ 0.726
Sex	$\tau =$ -0.197, $p =$ 0.278	$\tau =$ -0.173, $p =$ 0.346	$\tau =$ -0.047, $p =$ 0.794	$\tau =$ -0.169, $p =$ 0.350
Work or entertainment	$\tau =$ -0.429, $p =$ 0.005	$\tau =$ 0.071, $p =$ 0.649	$\tau =$ -0.134, $p =$ 0.381	$\tau =$ -0.134, $p =$ 0.381
Self-regulated learning	$\tau =$ 0.219, $p =$ 0.152	$\tau =$ -0.132, $p =$ 0.392	$\tau =$ 0.80, $p =$ 0.596	$\tau =$ -0.057, $p =$ 0.710
Computer affinity	$\tau =$ 0.142, $p =$ 0.353	$\tau =$ -0.079, $p =$ 0.611	$\tau =$ -0.327, $p =$ 0.032	$\tau =$ -0.045, $p =$ 0.770
Self-assessment A	$\tau =$ 0.187, $p =$ 0.222	$\tau =$ -0.058, $p =$ 0.708	$\tau =$ -0.064, $p =$ 0.671	$\tau =$ -0.048, $p =$ 0.750
Self-assessment B	$\tau =$ -0.034, $p =$ 0.837	$\tau =$ -0.035, $p =$ 0.836	$\tau =$ 0.180, $p =$ 0.277	$\tau =$ 0.083, $p =$ 0.617
Learning alone or in groups	$\tau =$ -0.267, $p =$ 0.135	$\tau =$ 0.110, $p =$ 0.542	$\tau =$ -0.062, $p =$ 0.727	$\tau =$ 0.250, $p =$ 0.162
ACT/REF	$\tau =$ -0.118, $p =$ 0.466	$\tau =$ 0.235, $p =$ 0.149	$\tau =$ -0.095, $p =$ 0.553	$\tau =$ -0.355, $p =$ 0.027
SEN/INT	$\tau =$ -0.009, $p =$ 0.957	$\tau =$ -0.268, $p =$ 0.100	$\tau =$ -0.196, $p =$ 0.222	$\tau =$ -0.179, $p =$ 0.265
VIS/VRB	$\tau =$ -0.058, $p =$ 0.721	$\tau =$ -0.256, $p =$ 0.121	$\tau =$ 0.120, $p =$ 0.459	$\tau =$ 0.152, $p =$ 0.350
SEQ/GLO	$\tau =$ 0.097, $p =$ 0.550	$\tau =$ -0.166, $p =$ 0.311	$\tau =$ 0.171, $p =$ 0.290	$\tau =$ -0.159, $p =$ 0.328

Table B.25: Correlation coefficient and significance value (significant for $p < 0.005$) of Kendall's τ for the first *FLAT Duisburg-Essen* survey (part 2).

FLAT DUE 1	Competencies A	Competencies B	Competencies Content
Age	$\tau =$ 0.240, $p = 0.197$	$\tau =$ -0.029, $p = 0.875$	$\tau =$ 0.174, $p = 0.303$
Sex	$\tau =$ -0.037, $p = 0.862$	$\tau =$ 0.176, $p = 0.410$	$\tau =$ 0.386, $p = 0.045$
Work or entertainment	$\tau =$ -0.083, $p = 0.642$	$\tau =$ -0.078, $p = 0.664$	$\tau =$ -0.067, $p = 0.681$
Self-regulated learning	$\tau =$ 0.132, $p = 0.457$	$\tau =$ 0.011, $p = 0.951$	$\tau =$ 0.549, $p = 0.001$
Computer affinity	$\tau =$ -0.099, $p = 0.577$	$\tau =$ 0.122, $p = 0.495$	$\tau =$ 0.102, $p = 0.529$
Self-assessment A	$\tau =$ 0.243, $p = 0.172$	$\tau =$ -0.320, $p = 0.072$	$\tau =$ 0.195, $p = 0.228$
Self-assessment B	$\tau =$ -0.133, $p = 0.493$	$\tau =$ 0.106, $p = 0.584$	$\tau =$ -0.171, $p = 0.332$
Learning alone or in groups	$\tau =$ 0.038, $p = 0.854$	$\tau =$ 0.115, $p = 0.581$	$\tau =$ -0.198, $p = 0.296$
ACT/REF	$\tau =$ 0.000, $p = 1.000$	$\tau =$ -0.260, $p = 0.166$	$\tau =$ 0.100, $p = 0.559$
SEN/INT	$\tau =$ 0.298, $p = 0.113$	$\tau =$ -0.269, $p = 0.154$	$\tau =$ 0.335, $p = 0.050$
VIS/VRB	$\tau =$ 0.147, $p = 0.443$	$\tau =$ -0.024, $p = 0.898$	$\tau =$ 0.005, $p = 0.977$
SEQ/GLO	$\tau =$ -0.078, $p = 0.681$	$\tau =$ -0.102, $p = 0.591$	$\tau =$ -0.246, $p = 0.153$
QCM - Interest	$\tau =$ 0.176, $p = 0.335$	$\tau =$ 0.108, $p = 0.554$	$\tau =$ 0.018, $p = 0.912$
QCM - Probability of success	$\tau =$ 0.040, $p = 0.826$	$\tau =$ 0.052, $p = 0.778$	$\tau =$ -0.088, $p = 0.599$
QCM - Anxiety	$\tau =$ 0.191, $p = 0.290$	$\tau =$ 0.146, $p = 0.419$	$\tau =$ -0.063, $p = 0.700$
QCM - Challenge	$\tau =$ 0.203, $p = 0.263$	$\tau =$ 0.400, $p = 0.027$	$\tau =$ -0.249, $p = 0.130$

Table B.26: Correlation coefficient and significance value (significant for $p < 0.005$) of Kendall's τ for the second *FLAT Duisburg-Essen* survey (part 1).

FLAT DUE 2	QCM Interest	QCM Probability of success	QCM Anxiety	QCM Challenge
Age	$\tau =$ 0.741, $p = 0.048$	$\tau =$ -0.386, $p = 0.306$	$\tau =$ -0.138, $p = 0.702$	$\tau =$ 0.214, $p = 0.559$
Sex	$\tau =$ -0.686, $p = 0.095$	$\tau =$ 0.612, $p = 0.140$	$\tau =$ -0.183, $p = 0.643$	$\tau =$ -0.189, $p = 0.639$
Work or entertainment	$\tau =$ -0.215, $p = 0.559$	$\tau =$ 0.000, $p = 1.000$	$\tau =$ -0.467, $p = 0.188$	$\tau =$ -0.552, $p = 0.126$
Self-regulated learning	$\tau =$ 0.215, $p = 0.559$	$\tau =$ -0.596, $p = 0.107$	$\tau =$ -0.067, $p = 0.851$	$\tau =$ 0.276, $p = 0.444$
Computer affinity	$\tau =$ 0.645, $p = 0.079$	$\tau =$ -0.596, $p = 0.107$	$\tau =$ -0.333, $p = 0.348$	$\tau =$ -0.276, $p = 0.444$
Self-assessment A	$\tau =$ 0.215, $p = 0.559$	$\tau =$ -0.596, $p = 0.107$	$\tau =$ -0.600, $p = 0.091$	$\tau =$ -0.552, $p = 0.126$
Self-assessment B	$\tau =$ 0.160, $p = 0.677$	$\tau =$ 0.000, $p = 1.000$	$\tau =$ 0.745, $p = 0.044$	$\tau =$ 0.386, $p = 0.306$
Learning alone or in groups	$\tau =$ -0.177, $p = 0.709$	$\tau =$ 0.667, $p = 0.147$	$\tau =$ 0.632, $p = 0.157$	$\tau =$ 0.167, $p = 0.717$
ACT/REF	$\tau =$ -0.148, $p = 0.692$	$\tau =$ 0.077, $p = 0.838$	$\tau =$ -0.552, $p = 0.126$	$\tau =$ -0.929, $p = 0.011$
SEN/INT	$\tau =$ -0.385, $p = 0.313$	$\tau =$ -0.320, $p = 0.405$	$\tau =$ -0.358, $p = 0.330$	$\tau =$ -0.074, $p = 0.843$
VIS/VRB	$\tau =$ -0.385, $p = 0.313$	$\tau =$ 0.000, $p = 1.000$	$\tau =$ 0.072, $p = 0.845$	$\tau =$ -0.296, $p = 0.428$
SEQ/GLO	$\tau =$ 0.000, $p = 1.000$	$\tau =$ 0.320, $p = 0.405$	$\tau =$ -0.072, $p = 0.845$	$\tau =$ -0.296, $p = 0.428$

Table B.27: Correlation coefficient and significance value (significant for $p < 0.005$) of Kendall's τ for the second *FLAT Duisburg-Essen* survey (part 2).

FLAT DUE 2	Competencies A	Competencies B	Competencies Content
Age	$\tau =$ 0.564, $p = 0.144$	$\tau =$ 0.239, $p = 0.552$	$\tau =$ 0.214, $p = 0.559$
Sex	$\tau =$ -0.213, $p = 0.617$	$\tau =$ -0.632, $p = 0.157$	$\tau =$ 0.283, $p = 0.481$
Work or entertainment	$\tau =$ 0.389, $p = 0.304$	$\tau =$ -0.346, $p = 0.380$	$\tau =$ 0.276, $p = 0.444$
Self-regulated learning	$\tau =$ 0.389, $p = 0.304$	$\tau =$ 0.577, $p = 0.143$	$\tau =$ 0.552, $p = 0.126$
Computer affinity	$\tau =$ 0.701, $p = 0.064$	$\tau =$ 0.115, $p = 0.770$	$\tau =$ 0.276, $p = 0.444$
Self-assessment A	$\tau =$ 0.389, $p = 0.304$	$\tau =$ 0.115, $p = 0.770$	$\tau =$ 0.276, $p = 0.444$
Self-assessment B	$\tau =$ -0.348, $p = 0.381$	$\tau =$ 0.387, $p = 0.351$	$\tau =$ -0.540, $p = 0.152$
Learning alone or in groups	$\tau =$ -0.530, $p = 0.264$	$\tau =$ -0.250, $p = 0.617$	$\tau =$ -0.632, $p = 0.157$
ACT/REF	$\tau =$ 0.161, $p = 0.676$	$\tau =$ -0.598, $p = 0.137$	$\tau =$ -0.071, $p = 0.846$
SEN/INT	$\tau =$ 0.334, $p = 0.396$	$\tau =$ 0.248, $p = 0.546$	$\tau =$ 0.741, $p = 0.048$
VIS/VRB	$\tau =$ -0.167, $p = 0.671$	$\tau =$ 0.000, $p = 1.000$	$\tau =$ -0.148, $p = 0.692$
SEQ/GLO	$\tau =$ -0.418, $p = 0.289$	$\tau =$ -0.496, $p = 0.228$	$\tau =$ -0.593, $p = 0.113$
QCM - Interest	$\tau =$ 0.334, $p = 0.396$	$\tau =$ 0.248, $p = 0.546$	$\tau =$ -0.148, $p = 0.692$
QCM - Probability of success	$\tau =$ -0.609, $p = 0.125$	$\tau =$ -0.645, $p = 0.120$	$\tau =$ -0.386, $p = 0.306$
QCM - Anxiety	$\tau =$ -0.545, $p = 0.150$	$\tau =$ 0.346, $p = 0.380$	$\tau =$ -0.414, $p = 0.251$
QCM - Challenge	$\tau =$ -0.242, $p = 0.531$	$\tau =$ 0.598, $p = 0.137$	$\tau =$ -0.071, $p = 0.846$

Table B.28: Correlation coefficient and significance value (significant for $p < 0.005$) of Kendall's τ for the third *FLAT Duisburg-Essen* survey (part 1).

FLAT DUE 3	QCM Interest	QCM Probability of success	QCM Anxiety	QCM Challenge
Age	$\tau =$ 0.333, $p = 0.497$	$\tau =$ -0.183, $p = 0.718$	$\tau =$ 0.000, $p = 1.000$	$\tau =$ 0.333, $p = 0.497$
Sex	$\tau =$ 0.236, $p = 0.655$	$\tau =$ -0.516, $p = 0.346$	$\tau =$ -0.707, $p = 0.180$	$\tau =$ -0.236, $p = 0.655$
Work or entertainment	$\tau =$ 0.000, $p = 1.000$	$\tau =$ -0.548, $p = 0.279$	$\tau =$ -1.000, $p =$ -	$\tau =$ -0.667, $p = 0.174$
Self-regulated learning	$\tau =$ 0.667, $p = 0.174$	$\tau =$ 0.183, $p = 0.718$	$\tau =$ 0.333, $p = 0.497$	$\tau =$ 0.667, $p = 0.174$
Computer affinity	$\tau =$ 0.333, $p = 0.497$	$\tau =$ -0.183, $p = 0.718$	$\tau =$ -0.667, $p = 0.174$	$\tau =$ -0.333, $p = 0.497$
Self-assessment A	$\tau =$ 0.333, $p = 0.497$	$\tau =$ -0.183, $p = 0.718$	$\tau =$ -0.667, $p = 0.174$	$\tau =$ -0.333, $p = 0.497$
Self-assessment B	$\tau =$ 0.333, $p = 0.497$	$\tau =$ -0.183, $p = 0.718$	$\tau =$ 0.000, $p = 1.000$	$\tau =$ 0.333, $p = 0.497$
Learning alone or in groups	$\tau =$ 0.707, $p = 0.180$	$\tau =$ 0.775, $p = 0.157$	$\tau =$ 0.707, $p = 0.180$	$\tau =$ 0.707, $p = 0.180$
ACT/REF	$\tau =$ -0.913, $p = 0.071$	$\tau =$ -0.400, $p = 0.444$	$\tau =$ -0.183, $p = 0.718$	$\tau =$ -0.548, $p = 0.279$
SEN/INT	$\tau =$ 0.183, $p = 0.718$	$\tau =$ 0.000, $p = 1.000$	$\tau =$ -0.548, $p = 0.279$	$\tau =$ -0.548, $p = 0.279$
VIS/VRB	$\tau =$ -0.333, $p = 0.497$	$\tau =$ -0.548, $p = 0.279$	$\tau =$ 0.000, $p = 1.000$	$\tau =$ 0.333, $p = 0.497$
SEQ/GLO	$\tau =$ 0.183, $p = 0.718$	$\tau =$ 0.800, $p = 0.126$	$\tau =$ 0.548, $p = 0.279$	$\tau =$ 0.183, $p = 0.718$

Table B.29: Correlation coefficient and significance value (significant for $p < 0.005$) of Kendall's τ for the third *FLAT Duisburg-Essen* survey (part 2).

FLAT DUE 3	Competencies A	Competencies B	Competencies Content
Age	$\tau =$ 0.707, $p = 0.180$	$\tau =$ 0.548, $p = 0.279$	$\tau =$ 0.548, $p = 0.279$
Sex	$\tau =$ 1.000, $p =$ -	$\tau =$ 0.775, $p = 0.157$	$\tau =$ 0.775, $p = 0.157$
Work or entertainment	$\tau =$ 0.707, $p = 0.180$	$\tau =$ 0.548, $p = 0.279$	$\tau =$ 0.548, $p = 0.279$
Self-regulated learning	$\tau =$ 0.236, $p = 0.655$	$\tau =$ 0.183, $p = 0.718$	$\tau =$ 0.183, $p = 0.718$
Computer affinity	$\tau =$ 0.707, $p = 0.180$	$\tau =$ 0.183, $p = 0.718$	$\tau =$ 0.183, $p = 0.718$
Self-assessment A	$\tau =$ 0.707, $p = 0.180$	$\tau =$ 0.183, $p = 0.718$	$\tau =$ 0.183, $p = 0.718$
Self-assessment B	$\tau =$ 0.707, $p = 0.180$	$\tau =$ 0.548, $p = 0.279$	$\tau =$ 0.548, $p = 0.279$
Learning alone or in groups	$\tau =$ -0.333, $p = 0.564$	$\tau =$ -0.516, $p = 0.346$	$\tau =$ -0.516, $p = 0.346$
ACT/REF	$\tau =$ -0.258, $p = 0.637$	$\tau =$ 0.000, $p = 1.000$	$\tau =$ 0.000, $p = 1.000$
SEN/INT	$\tau =$ 0.516, $p = 0.346$	$\tau =$ 0.000, $p = 1.000$	$\tau =$ 0.000, $p = 1.000$
VIS/VRB	$\tau =$ 0.236, $p = 0.655$	$\tau =$ 0.548, $p = 0.279$	$\tau =$ 0.548, $p = 0.279$
SEQ/GLO	$\tau =$ -0.775, $p = 0.157$	$\tau =$ -1.000, $p =$ -	$\tau =$ -1.000, $p =$ -
QCM - Interest	$\tau =$ 0.236, $p = 0.655$	$\tau =$ -0.183, $p = 0.718$	$\tau =$ -0.183, $p = 0.718$
QCM - Probability of success	$\tau =$ -0.516, $p = 0.346$	$\tau =$ -0.800, $p = 0.126$	$\tau =$ -0.800, $p = 0.126$
QCM - Anxiety	$\tau =$ -0.707, $p = 0.180$	$\tau =$ -0.548, $p = 0.279$	$\tau =$ -0.548, $p = 0.279$
QCM - Challenge	$\tau =$ -0.236, $p = 0.655$	$\tau =$ -0.183, $p = 0.718$	$\tau =$ -0.183, $p = 0.718$

Table B.30: Correlation coefficient and significance value (significant for $p < 0.005$) of Kendall's τ for the first *FLAT Potsdam* survey (part 1).

FLAT Potsdam 1	QCM Interest	QCM Probability of success	QCM Anxiety	QCM Challenge
Age	$\tau =$ 0.225, $p = 0.126$	$\tau =$ 0.237, $p = 0.116$	$\tau =$ 0.009, $p = 0.951$	$\tau =$ 0.012, $p = 0.934$
Sex	$\tau =$ 0.071, $p = 0.662$	$\tau =$ -0.043, $p = 0.797$	$\tau =$ 0.092, $p = 0.565$	$\tau =$ 0.198, $p = 0.222$
Work or entertainment	$\tau =$ -0.106, $p = 0.448$	$\tau =$ -0.220, $p = 0.124$	$\tau =$ -0.180, $p = 0.195$	$\tau =$ -0.173, $p = 0.216$
Self-regulated learning	$\tau =$ 0.016, $p = 0.905$	$\tau =$ 0.122, $p = 0.385$	$\tau =$ 0.173, $p = 0.204$	$\tau =$ 0.000, $p = 1.000$
Computer affinity	$\tau =$ 0.025, $p = 0.858$	$\tau =$ -0.245, $p = 0.082$	$\tau =$ -0.346, $p = 0.012$	$\tau =$ -0.129, $p = 0.350$
Self-assessment A	$\tau =$ 0.276, $p = 0.044$	$\tau =$ 0.085, $p = 0.544$	$\tau =$ 0.231, $p = 0.091$	$\tau =$ 0.091, $p = 0.512$
Self-assessment B	$\tau =$ 0.340, $p = 0.017$	$\tau =$ 0.079, $p = 0.591$	$\tau =$ 0.225, $p = 0.113$	$\tau =$ 0.119, $p = 0.404$
Learning alone or in groups	$\tau =$ 0.151, $p = 0.332$	$\tau =$ -0.029, $p = 0.858$	$\tau =$ 0.086, $p = 0.582$	$\tau =$ 0.166, $p = 0.290$
ACT/REF	$\tau =$ -0.233, $p = 0.106$	$\tau =$ 0.009, $p = 0.951$	$\tau =$ -0.029, $p = 0.840$	$\tau =$ -0.137, $p = 0.342$
SEN/INT	$\tau =$ 0.020, $p = 0.888$	$\tau =$ 0.060, $p = 0.682$	$\tau =$ -0.280, $p = 0.050$	$\tau =$ -0.216, $p = 0.135$
VIS/VRB	$\tau =$ 0.160, $p = 0.271$	$\tau =$ 0.148, $p = 0.321$	$\tau =$ -0.035, $p = 0.807$	$\tau =$ 0.054, $p = 0.714$
SEQ/GLO	$\tau =$ 0.114, $p = 0.429$	$\tau =$ 0.061, $p = 0.681$	$\tau =$ -0.023, $p = 0.871$	$\tau =$ -0.135, $p = 0.351$

Table B.31: Correlation coefficient and significance value (significant for $p < 0.005$) of Kendall's τ for the first *FLAT Potsdam* survey (part 2).

FLAT Potsdam 1	Competencies A	Competencies B	Competencies Content
Age	$\tau =$ 0.123, $p = 0.468$	$\tau =$ -0.104, $p = 0.529$	$\tau =$ -0.038, $p = 0.810$
Sex	$\tau =$ 0.068, $p = 0.716$	$\tau =$ -0.341, $p = 0.062$	$\tau =$ 0.008, $p = 0.961$
Work or entertainment	$\tau =$ -0.131, $p = 0.415$	$\tau =$ 0.025, $p = 0.874$	$\tau =$ 0.140, $p = 0.351$
Self-regulated learning	$\tau =$ -0.004, $p = 0.982$	$\tau =$ 0.066, $p = 0.669$	$\tau =$ -0.224, $p = 0.128$
Computer affinity	$\tau =$ -0.107, $p = 0.498$	$\tau =$ 0.059, $p = 0.702$	$\tau =$ 0.362, $p = 0.014$
Self-assessment A	$\tau =$ 0.161, $p = 0.309$	$\tau =$ -0.108, $p = 0.485$	$\tau =$ 0.000, $p = 1.000$
Self-assessment B	$\tau =$ 0.136, $p = 0.405$	$\tau =$ 0.133, $p = 0.407$	$\tau =$ -0.053, $p = 0.729$
Learning alone or in groups	$\tau =$ -0.108, $p = 0.550$	$\tau =$ -0.176, $p = 0.320$	$\tau =$ 0.086, $p = 0.608$
ACT/REF	$\tau =$ 0.163, $p = 0.324$	$\tau =$ 0.104, $p = 0.522$	$\tau =$ -0.020, $p = 0.898$
SEN/INT	$\tau =$ 0.159, $p = 0.336$	$\tau =$ 0.107, $p = 0.508$	$\tau =$ 0.268, $p = 0.082$
VIS/VRB	$\tau =$ 0.085, $p = 0.611$	$\tau =$ 0.117, $p = 0.476$	$\tau =$ -0.030, $p = 0.846$
SEQ/GLO	$\tau =$ 0.256, $p = 0.123$	$\tau =$ 0.321, $p = 0.049$	$\tau =$ -0.204, $p = 0.190$
QCM - Interest	$\tau =$ 0.224, $p = 0.166$	$\tau =$ -0.004, $p = 0.982$	$\tau =$ 0.045, $p = 0.766$
QCM - Probability of success	$\tau =$ 0.233, $p = 0.160$	$\tau =$ 0.160, $p = 0.324$	$\tau =$ -0.266, $p = 0.085$
QCM - Anxiety	$\tau =$ 0.233, $p = 0.147$	$\tau =$ -0.089, $p = 0.572$	$\tau =$ -0.201, $p = 0.182$
QCM - Challenge	$\tau =$ -0.055, $p = 0.733$	$\tau =$ -0.277, $p = 0.081$	$\tau =$ -0.026, $p = 0.865$

Table B.32: Correlation coefficient and significance value (significant for $p < 0.005$) of Kendall's τ for the second *FLAT Potsdam* survey (part 1).

FLAT Potsdam 2	QCM Interest	QCM Probability of success	QCM Anxiety	QCM Challenge
Age	$\tau =$ -0.012, $p = 0.955$	$\tau =$ 0.206, $p = 0.351$	$\tau =$ 0.000, $p = 1.000$	$\tau =$ -0.252, $p = 0.250$
Sex	$\tau =$ -0.176, $p = 0.448$	$\tau =$ -0.141, $p = 0.559$	$\tau =$ -0.088, $p = 0.704$	$\tau =$ -0.382, $p = 0.110$
Work or entertainment	$\tau =$ -0.069, $p = 0.739$	$\tau =$ -0.087, $p = 0.689$	$\tau =$ 0.139, $p = 0.505$	$\tau =$ 0.229, $p = 0.285$
Self-regulated learning	$\tau =$ 0.156, $p = 0.441$	$\tau =$ 0.036, $p = 0.865$	$\tau =$ -0.022, $p = 0.912$	$\tau =$ 0.082, $p = 0.696$
Computer affinity	$\tau =$ 0.191, $p = 0.349$	$\tau =$ -0.336, $p = 0.113$	$\tau =$ -0.326, $p = 0.110$	$\tau =$ -0.211, $p = 0.315$
Self-assessment A	$\tau =$ 0.156, $p = 0.441$	$\tau =$ -0.131, $p = 0.534$	$\tau =$ -0.313, $p = 0.124$	$\tau =$ -0.058, $p = 0.780$
Self-assessment B	$\tau =$ 0.559, $p = 0.006$	$\tau =$ 0.108, $p = 0.611$	$\tau =$ 0.134, $p = 0.509$	$\tau =$ 0.361, $p = 0.084$
Learning alone or in groups	$\tau =$ -0.055, $p = 0.809$	$\tau =$ 0.058, $p = 0.804$	$\tau =$ 0.055, $p = 0.809$	$\tau =$ 0.057, $p = 0.807$
ACT/REF	$\tau =$ 0.135, $p = 0.532$	$\tau =$ 0.157, $p = 0.484$	$\tau =$ 0.024, $p = 0.910$	$\tau =$ -0.153, $p = 0.490$
SEN/INT	$\tau =$ 0.168, $p = 0.430$	$\tau =$ -0.321, $p = 0.148$	$\tau =$ -0.312, $p = 0.143$	$\tau =$ -0.138, $p = 0.530$
VIS/VRB	$\tau =$ 0.416, $p = 0.053$	$\tau =$ -0.157, $p = 0.483$	$\tau =$ -0.245, $p = 0.255$	$\tau =$ -0.115, $p = 0.604$
SEQ/GLO	$\tau =$ 0.304, $p = 0.147$	$\tau =$ -0.150, $p = 0.491$	$\tau =$ 0.035, $p = 0.867$	$\tau =$ 0.085, $p = 0.692$

Table B.33: Correlation coefficient and significance value (significant for $p < 0.005$) of Kendall's τ for the second *FLAT Potsdam* survey (part 2).

FLAT Potsdam 2	Competencies A	Competencies B	Competencies Content
Age	$\tau =$ 0.136, $p =$ 0.565	$\tau =$ 0.028, $p =$ 0.904	$\tau =$ 0.052, $p =$ 0.815
Sex	$\tau =$ -0.110, $p =$ 0.670	$\tau =$ -0.068, $p =$ 0.789	$\tau =$ -0.016, $p =$ 0.948
Work or entertainment	$\tau =$ -0.101, $p =$ 0.661	$\tau =$ 0.188, $p =$ 0.408	$\tau =$ 0.112, $p =$ 0.607
Self-regulated learning	$\tau =$ 0.140, $p =$ 0.534	$\tau =$ 0.273, $p =$ 0.219	$\tau =$ 0.505, $p =$ 0.017
Computer affinity	$\tau =$ 0.056, $p =$ 0.803	$\tau =$ -0.261, $p =$ 0.241	$\tau =$ 0.218, $p =$ 0.307
Self-assessment A	$\tau =$ 0.336, $p =$ 0.136	$\tau =$ -0.013, $p =$ 0.953	$\tau =$ 0.553, $p =$ 0.009
Self-assessment B	$\tau =$ 0.420, $p =$ 0.062	$\tau =$ -0.247, $p =$ 0.266	$\tau =$ 0.192, $p =$ 0.365
Learning alone or in groups	$\tau =$ -0.068, $p =$ 0.786	$\tau =$ -0.191, $p =$ 0.444	$\tau =$ -0.455, $p =$ 0.055
ACT/REF	$\tau =$ 0.138, $p =$ 0.565	$\tau =$ 0.014, $p =$ 0.952	$\tau =$ 0.342, $p =$ 0.129
SEN/INT	$\tau =$ 0.256, $p =$ 0.280	$\tau =$ 0.223, $p =$ 0.338	$\tau =$ 0.348, $p =$ 0.117
VIS/VRB	$\tau =$ 0.077, $p =$ 0.749	$\tau =$ -0.100, $p =$ 0.672	$\tau =$ -0.013, $p =$ 0.953
SEQ/GLO	$\tau =$ 0.147, $p =$ 0.529	$\tau =$ 0.163, $p =$ 0.477	$\tau =$ 0.164, $p =$ 0.455
QCM - Interest	$\tau =$ 0.413, $p =$ 0.070	$\tau =$ -0.264, $p =$ 0.240	$\tau =$ 0.379, $p =$ 0.078
QCM - Probability of success	$\tau =$ -0.061, $p =$ 0.789	$\tau =$ -0.240, $p =$ 0.305	$\tau =$ -0.301, $p =$ 0.179
QCM - Anxiety	$\tau =$ -0.228, $p =$ 0.318	$\tau =$ 0.013, $p =$ 0.953	$\tau =$ -0.428, $p =$ 0.046
QCM - Challenge	$\tau =$ -0.104, $p =$ 0.659	$\tau =$ -0.055, $p =$ 0.812	$\tau =$ -0.127, $p =$ 0.564

Table B.34: Correlation coefficient and significance value (significant for $p < 0.005$) of Kendall's τ for the third *FLAT Potsdam* survey (part 1).

FLAT Potsdam 3	QCM Interest	QCM Probability of success	QCM Anxiety	QCM Challenge
Age	$\tau =$ 0.269, $p = 0.333$	$\tau =$ 0.355, $p = 0.221$	$\tau =$ 0.000, $p = 1.000$	$\tau =$ -0.188, $p = 0.510$
Sex	$\tau =$ 0.407, $p = 0.186$	$\tau =$ 0.000, $p = 1.000$	$\tau =$ 0.229, $p = 0.460$	$\tau =$ 0.283, $p = 0.370$
Work or entertainment	$\tau =$ -0.171, $p = 0.527$	$\tau =$ -0.216, $p = 0.445$	$\tau =$ -0.145, $p = 0.596$	$\tau =$ 0.269, $p = 0.333$
Self-regulated learning	$\tau =$ 0.141, $p = 0.600$	$\tau =$ 0.122, $p = 0.664$	$\tau =$ 0.229, $p = 0.399$	$\tau =$ -0.118, $p = 0.669$
Computer affinity	$\tau =$ 0.254, $p = 0.345$	$\tau =$ -0.061, $p = 0.828$	$\tau =$ 0.057, $p = 0.833$	$\tau =$ 0.412, $p = 0.134$
Self-assessment A	$\tau =$ 0.366, $p = 0.173$	$\tau =$ -0.243, $p = 0.385$	$\tau =$ 0.171, $p = 0.527$	$\tau =$ 0.471, $p = 0.087$
Self-assessment B	$\tau =$ 0.085, $p = 0.753$	$\tau =$ -0.426, $p = 0.128$	$\tau =$ -0.057, $p = 0.833$	$\tau =$ 0.118, $p = 0.669$
Learning alone or in groups	$\tau =$ -0.173, $p = 0.558$	$\tau =$ -0.335, $p = 0.276$	$\tau =$ -0.210, $p = 0.480$	$\tau =$ 0.036, $p = 0.905$
ACT/REF	$\tau =$ 0.096, $p = 0.738$	$\tau =$ 0.449, $p = 0.134$	$\tau =$ 0.194, $p = 0.502$	$\tau =$ -0.434, $p = 0.140$
SEN/INT	$\tau =$ 0.209, $p = 0.452$	$\tau =$ 0.226, $p = 0.436$	$\tau =$ -0.303, $p = 0.280$	$\tau =$ -0.188, $p = 0.510$
VIS/VRB	$\tau =$ 0.314, $p = 0.268$	$\tau =$ 0.068, $p = 0.819$	$\tau =$ -0.127, $p = 0.656$	$\tau =$ 0.000, $p = 1.000$
SEQ/GLO	$\tau =$ 0.030, $p = 0.914$	$\tau =$ -0.065, $p = 0.824$	$\tau =$ 0.424, $p = 0.130$	$\tau =$ 0.219, $p = 0.443$

Table B.35: Correlation coefficient and significance value (significant for $p < 0.005$) of Kendall's τ for the third *FLAT Potsdam* survey (part 2).

FLAT Potsdam 3	Competencies A	Competencies B	Competencies Content
Age	$\tau =$ 0.136, $p = 0.646$	$\tau =$ 0.119, $p = 0.698$	$\tau =$ -0.347, $p = 0.249$
Sex	$\tau =$ -0.514, $p = 0.119$	$\tau =$ -0.120, $p = 0.726$	$\tau =$ 0.419, $p = 0.211$
Work or entertainment	$\tau =$ 0.325, $p = 0.260$	$\tau =$ 0.416, $p = 0.163$	$\tau =$ 0.530, $p = 0.070$
Self-regulated learning	$\tau =$ 0.032, $p = 0.911$	$\tau =$ 0.447, $p = 0.130$	$\tau =$ 0.196, $p = 0.499$
Computer affinity	$\tau =$ 0.160, $p = 0.575$	$\tau =$ -0.149, $p = 0.613$	$\tau =$ -0.065, $p = 0.822$
Self-assessment A	$\tau =$ -0.032, $p = 0.911$	$\tau =$ 0.149, $p = 0.613$	$\tau =$ 0.392, $p = 0.176$
Self-assessment B	$\tau =$ -0.289, $p = 0.313$	$\tau =$ 0.373, $p = 0.207$	$\tau =$ 0.458, $p = 0.114$
Learning alone or in groups	$\tau =$ -0.039, $p = 0.901$	$\tau =$ -0.137, $p = 0.674$	$\tau =$ -0.400, $p = 0.210$
ACT/REF	$\tau =$ 0.327, $p = 0.286$	$\tau =$ 0.085, $p = 0.790$	$\tau =$ -0.074, $p = 0.812$
SEN/INT	$\tau =$ 0.136, $p = 0.646$	$\tau =$ 0.000, $p = 1.000$	$\tau =$ 0.208, $p = 0.489$
VIS/VRB	$\tau =$ -0.250, $p = 0.409$	$\tau =$ -0.291, $p = 0.353$	$\tau =$ -0.510, $p = 0.097$
SEQ/GLO	$\tau =$ 0.102, $p = 0.731$	$\tau =$ -0.316, $p = 0.301$	$\tau =$ -0.069, $p = 0.818$
QCM - Interest	$\tau =$ 0.000, $p = 1.000$	$\tau =$ -0.189, $p = 0.526$	$\tau =$ -0.099, $p = 0.734$
QCM - Probability of success	$\tau =$ -0.176, $p = 0.561$	$\tau =$ -0.286, $p = 0.359$	$\tau =$ -0.286, $p = 0.349$
QCM - Anxiety	$\tau =$ -0.165, $p = 0.572$	$\tau =$ -0.307, $p = 0.308$	$\tau =$ 0.000, $p = 1.000$
QCM - Challenge	$\tau =$ -0.408, $p = 0.169$	$\tau =$ -0.277, $p = 0.366$	$\tau =$ 0.104, $p = 0.729$

Table B.36: Correlation coefficient and significance value (significant for $p < 0.005$) of Kendall's τ for the first *ReSyst Berlin* survey (part 1).

ReSyst Berlin 1	QCM Interest	QCM Probability of success	QCM Anxiety	QCM Challenge
Age	$\tau =$ -0.036, $p = 0.72$	$\tau =$ 0.020, $p = 0.850$	$\tau =$ 0.118, $p = 0.245$	$\tau =$ -0.032, $p = 0.754$
Sex	$\tau =$ 0.258, $p = 0.025$	$\tau =$ 0.218, $p = 0.066$	$\tau =$ -0.108, $p = 0.350$	$\tau =$ -0.033, $p = 0.781$
Work or entertainment	$\tau =$ -0.239, $p = 0.014$	$\tau =$ 0.148, $p = 0.140$	$\tau =$ -0.109, $p = 0.264$	$\tau =$ -0.200, $p = 0.048$
Self-regulated learning	$\tau =$ 0.243, $p = 0.012$	$\tau =$ -0.089, $p = 0.372$	$\tau =$ -0.057, $p = 0.553$	$\tau =$ 0.187, $p = 0.056$
Computer affinity	$\tau =$ -0.180, $p = 0.063$	$\tau =$ -0.110, $p = 0.267$	$\tau =$ 0.078, $p = 0.419$	$\tau =$ 0.052, $p = 0.594$
Self-assessment A	$\tau =$ 0.094, $p = 0.336$	$\tau =$ 0.026, $p = 0.798$	$\tau =$ -0.029, $p = 0.770$	$\tau =$ 0.138, $p = 0.164$
Self-assessment B	$\tau =$ 0.009, $p = 0.926$	$\tau =$ -0.031, $p = 0.761$	$\tau =$ 0.045, $p = 0.648$	$\tau =$ -0.019, $p = 0.846$
Learning alone or in groups	$\tau =$ 0.155, $p = 0.175$	$\tau =$ -0.064, $p = 0.585$	$\tau =$ -0.003, $p = 0.978$	$\tau =$ -0.038, $p = 0.740$
ACT/REF	$\tau =$ -0.131, $p = 0.197$	$\tau =$ 0.233, $p = 0.025$	$\tau =$ -0.142, $p = 0.161$	$\tau =$ -0.234, $p = 0.023$
SEN/INT	$\tau =$ 0.238, $p = 0.018$	$\tau =$ 0.047, $p = 0.650$	$\tau =$ 0.046, $p = 0.647$	$\tau =$ -0.121, $p = 0.236$
VIS/VRB	$\tau =$ -0.057, $p = 0.578$	$\tau =$ 0.097, $p = 0.359$	$\tau =$ 0.049, $p = 0.632$	$\tau =$ -0.245, $p = 0.019$
SEQ/GLO	$\tau =$ -0.018, $p = 0.858$	$\tau =$ 0.011, $p = 0.919$	$\tau =$ 0.233, $p = 0.022$	$\tau =$ -0.006, $p = 0.950$

Table B.37: Correlation coefficient and significance value (significant for $p < 0.005$) of Kendall's τ for the first *ReSyst Berlin* survey (part 2).

ReSyst Berlin 1	Competencies A	Competencies B	Competencies Content
Age	$\tau =$ -0.135, $p = 0.263$	$\tau =$ 0.046, $p = 0.695$	$\tau =$ -0.191, $p = 0.079$
Sex	$\tau =$ 0.126, $p = 0.359$	$\tau =$ 0.017, $p = 0.901$	$\tau =$ 0.080, $p = 0.520$
Work or entertainment	$\tau =$ -0.006, $p = 0.961$	$\tau =$ 0.114, $p = 0.309$	$\tau =$ -0.116, $p = 0.266$
Self-regulated learning	$\tau =$ 0.038, $p = 0.742$	$\tau =$ -0.019, $p = 0.863$	$\tau =$ -0.141, $p = 0.173$
Computer affinity	$\tau =$ -0.140, $p = 0.222$	$\tau =$ -0.079, $p = 0.480$	$\tau =$ -0.152, $p = 0.140$
Self-assessment A	$\tau =$ 0.078, $p = 0.497$	$\tau =$ -0.039, $p = 0.730$	$\tau =$ -0.177, $p = 0.088$
Self-assessment B	$\tau =$ 0.223, $p = 0.055$	$\tau =$ 0.260, $p = 0.021$	$\tau =$ -0.115, $p = 0.274$
Learning alone or in groups	$\tau =$ 0.257, $p = 0.058$	$\tau =$ 0.171, $p = 0.194$	$\tau =$ 0.106, $p = 0.383$
ACT/REF	$\tau =$ -0.194, $p = 0.106$	$\tau =$ -0.109, $p = 0.352$	$\tau =$ 0.076, $p = 0.483$
SEN/INT	$\tau =$ 0.083, $p = 0.488$	$\tau =$ 0.063, $p = 0.591$	$\tau =$ 0.195, $p = 0.070$
VIS/VRB	$\tau =$ -0.107, $p = 0.380$	$\tau =$ 0.072, $p = 0.545$	$\tau =$ 0.144, $p = 0.191$
SEQ/GLO	$\tau =$ -0.024, $p = 0.845$	$\tau =$ 0.147, $p = 0.207$	$\tau =$ 0.032, $p = 0.768$
QCM - Interest	$\tau =$ 0.172, $p = 0.140$	$\tau =$ 0.122, $p = 0.281$	$\tau =$ 0.152, $p = 0.148$
QCM - Probability of success	$\tau =$ -0.070, $p = 0.557$	$\tau =$ 0.005, $p = 0.965$	$\tau =$ 0.016, $p = 0.880$
QCM - Anxiety	$\tau =$ -0.240, $p = 0.039$	$\tau =$ -0.124, $p = 0.273$	$\tau =$ -0.134, $p = 0.203$
QCM - Challenge	$\tau =$ 0.137, $p = 0.246$	$\tau =$ -0.220, $p = 0.056$	$\tau =$ -0.082, $p = 0.442$

Table B.38: Correlation coefficient and significance value (significant for $p < 0.005$) of Kendall's τ for the second *ReSyst Berlin* survey (part 1).

ReSyst Berlin 2	QCM Interest	QCM Probability of success	QCM Anxiety	QCM Challenge
Age	$\tau =$ 0.099, $p = 0.480$	$\tau =$ -0.092, $p = 0.524$	$\tau =$ 0.077, $p = 0.580$	$\tau =$ 0.130, $p = 0.357$
Sex	$\tau =$ 0.216, $p = 0.171$	$\tau =$ 0.225, $p = 0.167$	$\tau =$ -0.238, $p = 0.132$	$\tau =$ -0.220, $p = 0.169$
Work or entertainment	$\tau =$ -0.100, $p = 0.462$	$\tau =$ 0.056, $p = 0.689$	$\tau =$ -0.130, $p = 0.336$	$\tau =$ -0.119, $p = 0.383$
Self-regulated learning	$\tau =$ 0.063, $p = 0.638$	$\tau =$ -0.047, $p = 0.732$	$\tau =$ -0.121, $p = 0.366$	$\tau =$ 0.110, $p = 0.416$
Computer affinity	$\tau =$ -0.266, $p = 0.048$	$\tau =$ -0.103, $p = 0.457$	$\tau =$ 0.104, $p = 0.440$	$\tau =$ -0.144, $p = 0.289$
Self-assessment A	$\tau =$ 0.117, $p = 0.386$	$\tau =$ 0.032, $p = 0.819$	$\tau =$ -0.106, $p = 0.429$	$\tau =$ 0.170, $p = 0.212$
Self-assessment B	$\tau =$ -0.069, $p = 0.610$	$\tau =$ -0.053, $p = 0.702$	$\tau =$ 0.074, $p = 0.584$	$\tau =$ -0.174, $p = 0.204$
Learning alone or in groups	$\tau =$ 0.106, $p = 0.498$	$\tau =$ -0.011, $p = 0.944$	$\tau =$ -0.211, $p = 0.176$	$\tau =$ -0.226, $p = 0.153$
ACT/REF	$\tau =$ -0.043, $p = 0.760$	$\tau =$ 0.134, $p = 0.355$	$\tau =$ 0.077, $p = 0.580$	$\tau =$ -0.160, $p = 0.259$
SEN/INT	$\tau =$ 0.211, $p = 0.129$	$\tau =$ 0.003, $p = 0.985$	$\tau =$ -0.153, $p = 0.271$	$\tau =$ -0.182, $p = 0.195$
VIS/VRB	$\tau =$ -0.049, $p = 0.729$	$\tau =$ 0.117, $p = 0.425$	$\tau =$ 0.109, $p = 0.441$	$\tau =$ -0.242, $p = 0.093$
SEQ/GLO	$\tau =$ 0.003, $p = 0.985$	$\tau =$ -0.025, $p = 0.863$	$\tau =$ 0.117, $p = 0.402$	$\tau =$ 0.089, $p = 0.528$

Table B.39: Correlation coefficient and significance value (significant for $p < 0.005$) of Kendall's τ for the second *ReSyst Berlin* survey (part 2).

ReSyst Berlin 2	Competencies A	Competencies B	Competencies Content
Age	$\tau =$ -0.229, $p = 0.143$	$\tau =$ 0.013, $p = 0.934$	$\tau =$ -0.315, $p = 0.031$
Sex	$\tau =$ 0.300, $p = 0.090$	$\tau =$ 0.183, $p = 0.301$	$\tau =$ 0.233, $p = 0.158$
Work or entertainment	$\tau =$ -0.075, $p = 0.619$	$\tau =$ -0.009, $p = 0.951$	$\tau =$ -0.054, $p = 0.701$
Self-regulated learning	$\tau =$ -0.062, $p = 0.679$	$\tau =$ 0.171, $p = 0.253$	$\tau =$ 0.212, $p = 0.130$
Computer affinity	$\tau =$ -0.357, $p = 0.017$	$\tau =$ -0.077, $p = 0.610$	$\tau =$ -0.145, $p = 0.301$
Self-assessment A	$\tau =$ -0.031, $p = 0.836$	$\tau =$ 0.083, $p = 0.581$	$\tau =$ 0.127, $p = 0.368$
Self-assessment B	$\tau =$ -0.191, $p = 0.206$	$\tau =$ 0.300, $p = 0.047$	$\tau =$ 0.092, $p = 0.514$
Learning alone or in groups	$\tau =$ -0.250, $p = 0.153$	$\tau =$ 0.115, $p = 0.512$	$\tau =$ -0.047, $p = 0.776$
ACT/REF	$\tau =$ 0.141, $p = 0.369$	$\tau =$ -0.258, $p = 0.099$	$\tau =$ 0.133, $p = 0.363$
SEN/INT	$\tau =$ 0.055, $p = 0.723$	$\tau =$ 0.246, $p = 0.113$	$\tau =$ 0.238, $p = 0.101$
VIS/VRB	$\tau =$ 0.094, $p = 0.555$	$\tau =$ 0.076, $p = 0.632$	$\tau =$ 0.006, $p = 0.969$
SEQ/GLO	$\tau =$ 0.058, $p = 0.707$	$\tau =$ -0.006, $p = 0.967$	$\tau =$ -0.118, $p = 0.417$
QCM - Interest	$\tau =$ 0.311, $p = 0.042$	$\tau =$ 0.150, $p = 0.325$	$\tau =$ 0.080, $p = 0.577$
QCM - Probability of success	$\tau =$ 0.142, $p = 0.368$	$\tau =$ -0.294, $p = 0.063$	$\tau =$ 0.026, $p = 0.861$
QCM - Anxiety	$\tau =$ -0.235, $p = 0.125$	$\tau =$ 0.078, $p = 0.609$	$\tau =$ -0.071, $p = 0.617$
QCM - Challenge	$\tau =$ -0.003, $p = 0.983$	$\tau =$ -0.105, $p = 0.497$	$\tau =$ -0.075, $p = 0.602$

Table B.40: Correlation coefficient and significance value (significant for $p < 0.005$) of Kendall's τ for the third *ReSyst Berlin* survey (part 1).

ReSyst Berlin 3	QCM Interest	QCM Probability of success	QCM Anxiety	QCM Challenge
Age	$\tau =$ 0.084, $p = 0.573$	$\tau =$ 0.217, $p = 0.162$	$\tau =$ 0.091, $p = 0.542$	$\tau =$ 0.312, $p = 0.039$
Sex	$\tau =$ 0.291, $p = 0.080$	$\tau =$ 0.189, $p = 0.277$	$\tau =$ -0.222, $p = 0.183$	$\tau =$ -0.164, $p = 0.332$
Work or entertainment	$\tau =$ -0.263, $p = 0.066$	$\tau =$ -0.071, $p = 0.636$	$\tau =$ -0.038, $p = 0.790$	$\tau =$ -0.172, $p = 0.238$
Self-regulated learning	$\tau =$ 0.232, $p = 0.102$	$\tau =$ 0.166, $p = 0.261$	$\tau =$ -0.198, $p = 0.163$	$\tau =$ 0.035, $p = 0.807$
Computer affinity	$\tau =$ -0.261, $p = 0.066$	$\tau =$ -0.003, $p = 0.982$	$\tau =$ 0.057, $p = 0.690$	$\tau =$ -0.038, $p = 0.790$
Self-assessment A	$\tau =$ 0.019, $p = 0.894$	$\tau =$ -0.273, $p = 0.065$	$\tau =$ -0.154, $p = 0.278$	$\tau =$ 0.134, $p = 0.350$
Self-assessment B	$\tau =$ -0.094, $p = 0.507$	$\tau =$ -0.033, $p = 0.822$	$\tau =$ -0.224, $p = 0.116$	$\tau =$ -0.128, $p = 0.374$
Learning alone or in groups	$\tau =$ 0.141, $p = 0.393$	$\tau =$ 0.077, $p = 0.655$	$\tau =$ -0.166, $p = 0.312$	$\tau =$ -0.287, $p = 0.086$
ACT/REF	$\tau =$ -0.010, $p = 0.946$	$\tau =$ 0.106, $p = 0.494$	$\tau =$ 0.124, $p = 0.406$	$\tau =$ 0.048, $p = 0.752$
SEN/INT	$\tau =$ 0.127, $p = 0.384$	$\tau =$ 0.125, $p = 0.415$	$\tau =$ -0.249, $p = 0.090$	$\tau =$ -0.303, $p = 0.041$
VIS/VRB	$\tau =$ 0.131, $p = 0.380$	$\tau =$ 0.263, $p = 0.091$	$\tau =$ -0.017, $p = 0.910$	$\tau =$ -0.182, $p = 0.230$
SEQ/GLO	$\tau =$ -0.262, $p = 0.080$	$\tau =$ 0.007, $p = 0.964$	$\tau =$ 0.195, $p = 0.192$	$\tau =$ 0.062, $p = 0.684$

Table B.41: Correlation coefficient and significance value (significant for $p < 0.005$) of Kendall's τ for the third *ReSyst Berlin* survey (part 2).

ReSyst Berlin 3	Competencies A	Competencies B	Competencies Content
Age	$\tau =$ -0.225, $p = 0.183$	$\tau =$ -0.156, $p = 0.373$	$\tau =$ -0.066, $p = 0.685$
Sex	$\tau =$ 0.213, $p = 0.262$	$\tau =$ -0.030, $p = 0.880$	$\tau =$ 0.492, $p = 0.007$
Work or entertainment	$\tau =$ -0.053, $p = 0.743$	$\tau =$ 0.338, $p = 0.045$	$\tau =$ 0.172, $p = 0.271$
Self-regulated learning	$\tau =$ 0.073, $p = 0.651$	$\tau =$ -0.227, $p = 0.173$	$\tau =$ 0.098, $p = 0.528$
Computer affinity	$\tau =$ -0.295, $p = 0.066$	$\tau =$ -0.120, $p = 0.471$	$\tau =$ -0.229, $p = 0.141$
Self-assessment A	$\tau =$ 0.178, $p = 0.268$	$\tau =$ 0.030, $p = 0.857$	$\tau =$ 0.134, $p = 0.387$
Self-assessment B	$\tau =$ -0.203, $p = 0.208$	$\tau =$ 0.129, $p = 0.440$	$\tau =$ 0.378, $p = 0.015$
Learning alone or in groups	$\tau =$ -0.082, $p = 0.660$	$\tau =$ 0.163, $p = 0.402$	$\tau =$ 0.231, $p = 0.200$
ACT/REF	$\tau =$ -0.004, $p = 0.980$	$\tau =$ 0.360, $p = 0.040$	$\tau =$ 0.104, $p = 0.522$
SEN/INT	$\tau =$ 0.118, $p = 0.478$	$\tau =$ -0.018, $p = 0.918$	$\tau =$ 0.083, $p = 0.604$
VIS/VRB	$\tau =$ -0.004, $p = 0.980$	$\tau =$ 0.101, $p = 0.566$	$\tau =$ 0.101, $p = 0.536$
SEQ/GLO	$\tau =$ -0.099, $p = 0.557$	$\tau =$ -0.101, $p = 0.566$	$\tau =$ -0.197, $p = 0.226$
QCM - Interest	$\tau =$ 0.234, $p = 0.151$	$\tau =$ -0.026, $p = 0.877$	$\tau =$ 0.007, $p = 0.963$
QCM - Probability of success	$\tau =$ -0.096, $p = 0.573$	$\tau =$ -0.143, $p = 0.418$	$\tau =$ 0.000, $p = 1.000$
QCM - Anxiety	$\tau =$ -0.066, $p = 0.686$	$\tau =$ 0.013, $p = 0.938$	$\tau =$ -0.063, $p = 0.690$
QCM - Challenge	$\tau =$ 0.101, $p = 0.543$	$\tau =$ -0.071, $p = 0.679$	$\tau =$ -0.120, $p = 0.451$

Table B.42: Correlation coefficient and significance value (significant for $p < 0.005$) of Kendall's τ for visual/verbal learning style and preferences for text or video usage.

Study	n	Correlation Visual/Verbal and Usage of Text or Video
FLAT Berlin 2	19	τ = -0.228, $p = 0.218$
FLAT Berlin 3	21	$\tau = 0.000$, $p = 1.000$
FLAT Potsdam 2	3	-
FLAT Potsdam 3	4	τ = -0.548, $p = 0.279$
ReSyst Berlin 2	12	$\tau = 0.159$, $p = 0.511$
ReSyst Berlin 3	13	τ = -0.056, $p = 0.802$

Appendix C

Conversion ILS-values to Integers

Table C.1 explains the conversion for the values of the "index of learning styles" questionnaire to integer values, which are more easily usable for statistical analysis. By construction, zero is no possible outcome for the scales of this questionnaire.

Table C.1: Conversion table from ILS-values to integers.

ILS-values	**11a**	**10a**	**9a**	**8a**	**7a**	**6a**	**5a**	**4a**	**3a**	**2a**	**1a**
Conversion results	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1
ILS-values	**1b**	**2b**	**3b**	**4b**	**5b**	**6b**	**7b**	**8b**	**9b**	**10b**	**11b**
Conversion results	1	2	3	4	5	6	7	8	9	10	11

Appendix D

Qualitative Content Analysis

D.1 Interview Guidelines

This section presents the short guidelines for the semi-structured interviews. If necessary, the questions were further explained to help the students understand their correct meaning.

Each interview, at the study location as well as via e-mail, chat or video chat started with a short introduction to help students understand that the purpose of these interviews was to find out how they felt about using the Learning Units and to get more information on strengths and weaknesses of the whole system. Afterwards, the following questions were posed in German:

- Was hat dich motiviert an der Studie teilzunehmen?
- Wie (und wieviel) hast du die Lerneinheit genutzt?
- Was sind aus deiner Sicht Stärken der Lerneinheit?
- Was sind aus deiner Sicht Schwächen der Lerneinheit?
- Es haben nur sehr wenige aus dem Kurs teilgenommen. Hast du Ideen, warum manche nicht teilnehmen wollten?
- Hast du die Bonusseiten freigeschaltet?
- Haben dir die Lerneinheiten geholfen, den Stoff zu verstehen?
- Hast du Anmerkungen zu den Umfragen oder sonstige Anmerkungen zur Studie?

The questions translate to the following:

- What was your motivation to participate in the study?

- How much did you use the Learning Units?
- From your point of view: What are strengths of these Learning Units?
- From your point of view: What are weaknesses of these Learning Units?
- Overall, the participation rate was low. Do you have ideas what possible reasons for this could be?
- Did you unlock the bonus pages?
- Did the Learning Units help you in understanding the content?
- Do you have any additional comments about the Learning Units or the study?

D.2 Analysis Examples

Table D.1 shows two actual examples of the qualitative content analysis on the interviews.

Table D.1: Examples of qualitative content analysis.

Original text	Paraphrasing	Generalization	Category
Also eine Stärke ist, dass es halt Information on demand ist also man kann es halt jedes Mal sich wieder anschauen. Das ist bei Vorlesungsinhalten nicht immer so wenn man nicht dagewesen ist.	One strength is information on demand, especially useful if the student has not been in the lecture	Information on demand	**Strengths of the Learning Unit**
Quasi wenn man einmal in dem Text drin ist in der Lerneinheit zu einem Thema, dann ist das teilweise recht schwer nochmal den Überblick zu behalten	It was not easy for the student to keep an overview	Insufficient overview	**Usability issues with the platform**

Appendix E

Example Questionnaires

This chapter contains questionnaires for all three regular surveys, taken from the *ReSyst Berlin* study, and additionally the follow-up surveys for this study. As the regular surveys are all similar (apart from the content questions), these surveys can be seen as exemplary for all studies.

E.1 First Questionnaire

Seite 01

Herzlich willkommen! In dieser Befragung soll es darum gehen, mehr darüber zu erfahren, wie du lernst und wie dein Vorwissen zum behandelten Stoff der nächsten Wochen ist.

Die Umfrage dauert ungefähr 20 Minuten.

Bitte beantworte die Fragen wahrheitsgemäß, um ein möglichst aussagekräftiges Ergebnis der Studie zu ermöglichen.

Wenn du bei inhaltlichen Fragen die Lösung nicht weißt, gibt es dafür immer eine explizite Option.
Bitte nicht raten.

Sämtliche Daten werden anonymisiert erhoben und ausschließlich zu Forschungszwecken verwendet.

Die Antworten haben keinerlei Auswirkung auf deine Bewertung in der Veranstaltung.

Vielen Dank, dass du dir die Zeit nimmst!
Arno

Auf dieser Seite wollen wir Tendenzen abfragen, wie du am liebsten lernst. Je stärker du also zu einer Seite tendierst, umso näher platziere bitte dort den Schieberegler.

	allein	in einer Gruppe
Ich lerne am liebsten...		
	zu zweit	mit mehr als fünf Leuten
Wenn ich mit anderen lerne, dann am liebsten...		
	kaum aus	sehr gut aus
Mit Programmen wie Word und Excel kenne ich mich...		

	< 5 Stunden	5 – 10 Stunden	10 – 20 Stunden	> 20 Stunden
Am PC verbringe ich pro Woche ...	○	○	○	○

	ein nützliches Werkzeug	unverzichtbar
Für mich ist der Computer...		
	zum Lernen und Arbeiten	zur Unterhaltung
Für mich dient der Computer hauptsächlich...		
	mit Papiernotizen	mit dem Computer
Ich lerne am liebsten...		
	kurz vor der Prüfung	kontinuierlich über das Semester verteilt
Ich lerne meistens...		
	wöchentliche Hausaufgaben	wenige größere Hausaufgaben
Ich bevorzuge...		
	trifft voll zu	trifft nicht zu
Wenn ich etwas nicht verstehe, besorge ich mir selbständig weiteres Lernmaterial.		
	trifft voll zu	trifft nicht zu
Ich bin im Umgang mit mindestens einem Lernmanagementsystem (L^2P, ISIS, Moodle, Blackboard...) vertraut.		
	trifft voll zu	trifft nicht zu
Alle Inhalte die ich lerne, prüfe ich auch kritisch.		

Auf dieser Seite siehst du einige Fragen zu deinem Wissen rund um die Veranstaltung 'Reaktive Systeme'. Du bekommst die Aufgaben auf dieser Seite später erneut und wirst dann gebeten sie zu beantworten.
Lies dir nun erstmal die folgenden vier Aufgaben in Ruhe durch und überlege dir, wie du sie lösen würdest.

Gegeben sei eine monotone Funktion $f : D \to D$ und ein vollständiger Verband $(D, \sqsubseteq)$ mit $D \triangleq 2^A$ für eine endliche Menge A.

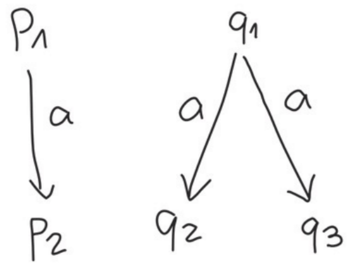
Was ist der größte Fixpunkt von f für ein passendes m aus den natürlichen Zahlen?

Welche der folgenden Formeln beschreibt Monotonie?

- $\forall d \in D.\, d \sqsubseteq f(d)$
- $\forall d \in D. \forall d' \in D.\, d \sqsubseteq d' \to f(d) \sqsubseteq f(d')$
- $\forall d \in D.\, f(d) \sqsubseteq d$

Angenommen ein Prozess p_1 ist stark bisimilar zu einem anderen Prozess p_2. Welche Äquivalenzen gelten dann noch?

Gegeben sei das folgende LTS:



Was ist eine passende Bisimulationsrelation um zu zeigen, dass $p_1 \sim q_1$?

- $\{(p_1, q_1), (p_2, q_2), (p_2, q_3)\}$
- $\{(p_1, q_1), (p_2, q_2)\}$
- $\{p_1, q_1, p_2, q_2, q_3\}$
- $\{p_1, q_1, p_2, q_2\}$

1. Nun wollen wir wissen, wie deine momentane Einstellung zu den beschriebenen Aufgaben ist. Dazu findest du auf dieser Seite Aussagen. Markiere bitte das Feld, das auf dich am Besten passt.

	Trifft nicht zu						Trifft zu
Ich mag solche Rätsel und Knobeleien.	○	○	○	○	○	○	○
Ich glaube, der Schwierigkeit dieser Aufgaben gewachsen zu sein.	○	○	○	○	○	○	○
Wahrscheinlich werde ich die Aufgaben nicht schaffen.	○	○	○	○	○	○	○
Bei den Aufgaben mag ich die Rolle des Wissenschaftlers, der Zusammenhänge entdeckt.	○	○	○	○	○	○	○
Ich fühle mich unter Druck, bei den Aufgaben gut abschneiden zu müssen.	○	○	○	○	○	○	○
Die Aufgaben sind eine richtige Herausforderung für mich.	○	○	○	○	○	○	○
Nach dem Lesen der Instruktion erscheinen mir die Aufgaben sehr interessant.	○	○	○	○	○	○	○
Ich bin sehr gespannt darauf, wie gut ich hier abschneiden werde.	○	○	○	○	○	○	○
Ich fürchte mich ein wenig davor, dass ich mich hier blamieren könnte.	○	○	○	○	○	○	○
Ich bin fest entschlossen, mich bei diesen Aufgaben voll anzustrengen.	○	○	○	○	○	○	○
Bei Aufgaben wie diesen brauche ich keine Belohnung, sie machen mir auch so viel Spaß.	○	○	○	○	○	○	○
Es ist mir etwas peinlich, hier zu versagen.	○	○	○	○	○	○	○
Ich glaube, das kann jeder schaffen.	○	○	○	○	○	○	○
Ich glaube, ich schaffe diese Aufgaben nicht.	○	○	○	○	○	○	○
Wenn ich die Aufgaben schaffe, werde ich schon ein wenig stolz auf meine Tüchtigkeit sein.	○	○	○	○	○	○	○
Wenn ich an die Aufgaben denke, bin ich etwas beunruhigt.	○	○	○	○	○	○	○
Solche Aufgaben würde ich auch in meiner Freizeit bearbeiten.	○	○	○	○	○	○	○
Die konkreten Leistungsanforderungen hier lähmen mich.	○	○	○	○	○	○	○

Als nächstes würden wir gern etwas über deinen Wissensstand zu bestimmten Bereichen erfahren, egal ob sie bereits Teil des Studiums waren oder noch nicht.

Hinweis: Bei einer der Fragen sind auch Mehrfachantworten möglich.

	weiß ich gar nichts darüber — kann ich sehr gut
Calculus of Communicating Systems (CCS)	
Starke und schwache Bisimulation	
partielle Ordnungen und Verbände	
Fixpunkte	
Berechnung von Fixpunkten auf Verbänden	

2. Gegeben sei eine monotone Funktion $f : D \to D$ und ein vollständiger Verband $(D, \sqsubseteq)$ mit $D \triangleq 2^A$ für eine endliche Menge A.

   Was ist der größte Fixpunkt von f für ein passendes m aus den natürlichen Zahlen?

- ○ $f^m(A)$
- ○ $f^m(A \times A)$
- ○ $f^m(2^A)$
- ○ $f^m(2^{A \times A})$

- ○ weiß nicht

3. Welche der folgenden Formeln beschreibt Monotonie?

- ○ $\forall d \in D.\, d \sqsubseteq f(d)$
- ○ $\forall d \in D. \forall d' \in D.\, d \sqsubseteq d' \to f(d) \sqsubseteq f(d')$
- ○ $\forall d \in D.\, f(d) \sqsubseteq d$

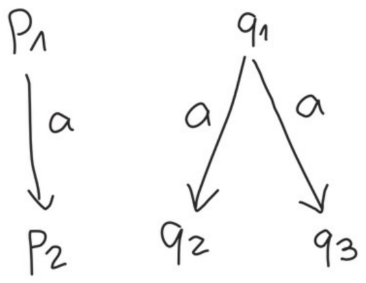
- ○ weiß nicht

4. Angenommen ein Prozess p_1 ist stark bisimilar zu einem anderen Prozess p_2. Welche Äquivalenzen gelten dann noch?

- ☐ $p_2 \sim p_1$
- ☐ $p_1 \approx p_2$
- ☐ $Traces(p_1) = Traces(p_2)$

- ☐ weiß nicht

5. Gegeben sei das folgende LTS:



Was ist eine passende Bisimulationsrelation um zu zeigen, dass $p_1 \sim q_1$?

- ○ $\{(p_1, q_1), (p_2, q_2), (p_2, q_3)\}$
- ○ $\{(p_1, q_1), (p_2, q_2)\}$
- ○ $\{p_1, q_1, p_2, q_2, q_3\}$
- ○ $\{p_1, q_1, p_2, q_2\}$

- ○ weiß nicht

Als nächstes möchten wir noch mehr über dein Vorwissen im Bereich rund um Potenzmengen erfahren, egal ob diese bereits Teil deines Studiums waren oder nicht.

Hinweis: Bei zwei Fragen sind auch Mehrfachantworten möglich.

6. $\{\} \in \mathcal{P}(\emptyset)$

- ◯ wahr
- ◯ falsch

- ◯ weiß nicht

7. $\{\} \subseteq \mathcal{P}(\emptyset)$

- ◯ wahr
- ◯ falsch

- ◯ weiß nicht

8. Sei A eine beliebige Menge. Es gilt immer

$A \subseteq \mathcal{P}(A)$

- ◯ wahr
- ◯ falsch

- ◯ weiß nicht

9. Welche der folgenden Mengen sind Element von $\mathcal{P}(\{x, y\})$?

- ☐ $\emptyset$
- ☐ $\{x\}$
- ☐ $\{y\}$
- ☐ $\{x, y\}$

- ☐ weiß nicht

10. Welche der folgenden Mengen sind Teilmenge von $\mathcal{P}(\{x, y\})$?

- ☐ $\emptyset$
- ☐ $\{x\}$
- ☐ $\{y\}$
- ☐ $\{x, y\}$

- ☐ weiß nicht

Im Folgenden wollen wir noch mehr darüber erfahren, wie du gerne lernst. Sollten beide Antworten für dich in Frage kommen wähle die aus, die in deinen Kursen tendenziell häufiger auf dich zutrifft.

11. Ich verstehe eine Sache besser, wenn ich sie

- ◯ ausprobiere.
- ◯ durchdenke.

12. Ich würde lieber

- ◯ als sachlich empfunden werden.
- ◯ als erfinderisch empfunden werden.

13. Wenn ich darüber nachdenke, was ich am Vortag gemacht habe, habe ich am ehesten

- ◯ ein Bild vor Augen.
- ◯ einen Text im Kopf.

14. Ich tendiere dazu

- ◯ Details zu einem Thema zu verstehen, während ich ein unscharfes Bild von der Gesamtstruktur habe.
- ◯ die Gesamtstruktur eines Themas zu erfassen, während ich eher unsicher bezüglich konkreter Details bin.

15. Wenn ich etwas neues lerne, hilft es mir,

- ◯ darüber zu reden.
- ◯ darüber nachzudenken.

16. Wenn ich Dozent wäre, würde ich lieber einen Kurs geben,

- ◯ der sich mit Fakten und realen Situationen beschäftigt.
- ◯ der sich mit Ideen und Theorien beschäftigt.

17. Mir ist es lieber, wenn mir neue Informationen mittels

- ◯ Bildern, Diagrammen, Graphen und Karten vermittelt werden.
- ◯ schriftlicher Beschreibungen oder mündlich vermittelt werden.

18. Wenn ich einmal,

- ◯ die einzelnen Komponenten verstanden habe, verstehe ich den gesamten Komplex.
- ◯ den Gesamtkomplex verstanden habe, erkenne ich, wie sich die einzelnen Komponenten ineinander fügen.

19. In einer Gruppenarbeit zu einem schwierigen Thema bin ich eher jemand, der

- ◯ sofort loslegt und Ideen einwirft.
- ◯ sich erst einmal zurücknimmt und zuhört.

20. Mir fällt es leichter,

- ◯ Fakten zu lernen.
- ◯ Konzepte zu lernen.

21. In einem Buch mit vielen Bildern und Diagrammen

- ◯ betrachte ich eher die Bilder und Diagramme sorgfältig.
- ◯ konzentriere ich mich eher auf den Text.

22. Beim Lösen mathematischer Aufgaben

- ◯ arbeite ich mich normalerweise Schritt für Schritt zur Lösung voran.
- ◯ weiß ich oft recht schnell die Antwort, aber habe Schwierigkeiten die Lösungsschritte dorthin zu finden.

23. Wenn ich an einem Kurs teilgenommen habe,

- ◯ habe ich meist viele Kommilitonen kennen gelernt.
- ◯ habe ich selten viele Kommilitonen kennen gelernt.

24. Wenn ich Sachliteratur lese, bevorzuge ich Texte,

- ◯ aus denen ich neue Fakten ziehen oder Fertigkeiten lernen kann.
- ◯ die mir neue Denkanstöße geben.

25. Ich mag es, wenn Dozenten

- ◯ viele Diagramme zur Illustration verwenden.
- ◯ viel Zeit auf mündliche Erklärungen verwenden.

26. Wenn ich eine Geschichte oder einen Roman analysiere,

- ◯ denke ich die einzelnen Ereignisse durch, um die Schwerpunktthemen herauszufinden.
- ◯ weiß ich nach dem Lesen nur, welche Schwerpunktthemen es gibt, und muss rückblickend die einzelnen Ereignisse entsprechend zuordnen.

27. Wenn ich eine Hausaufgabe angehe,

- ◯ beginne ich sofort mit der Suche nach der Lösung.
- ◯ versuche ich zuerst, das Problem voll und ganz zu verstehen.

28. Ich bevorzuge die Vorstellung von

- ◯ Gewissheit.
- ◯ Theorien.

29. Ich erinnere mich am besten an etwas,

- ◯ das ich sehe.
- ◯ das ich höre.

30. Für mich ist es wichtiger, dass ein Dozent

- ◯ Inhalte in klaren, fortlaufenden Schritten vermittelt.
- ◯ einen allgemeinen Überblick liefert und Bezüge zu anderen Themenfeldern herstellt.

31. Ich lerne am liebsten

- ◯ in Lerngruppen.
- ◯ allein.

32. Ich gelte eher als jemand,

- ◯ der bei seiner Arbeit Wert auf die Details legt.
- ◯ der kreativ an seine Arbeit herangeht.

33. Als Wegbeschreibung zu einem mir unbekannten Ort bevorzuge ich

- ◯ eine Karte.
- ◯ schriftliche Instruktionen.

34. Ich lerne

- ◯ in recht konstantem Tempo. Wenn ich fleißig lerne, „schnalle“ ich es.
- ◯ stoßweise. Ich bin vollkommen verwirrt, und dann macht es plötzlich „Klick“.

35. Ich würde eher

- ◯ eine Sache ausprobieren.
- ◯ darüber nachdenken, wie ich eine Sache angehe.

36. Wenn ich zum Vergnügen lese, mag ich Autoren,

- ◯ die klar und deutlich sagen, was sie meinen.
- ◯ die sich eines kreativen und interessanten Ausdrucks bedienen.

37. Wenn ich im Unterricht ein Diagramm oder eine Skizze sehe, erinnere ich mich am ehesten

- ◯ an das Bild.
- ◯ an das, was der Dozent dazu gesagt hat.

38. Wenn ich mich mit einem Themenkomplex befasse,

- ◯ fokussiere ich mich eher auf Details und habe kein Gesamtbild im Kopf.
- ◯ versuche ich eher das Gesamtbild zu verstehen, bevor ich mich den Details widme.

39. Ich erinnere mich besser an etwas,

- ◯ das ich getan habe.
- ◯ über das ich viel nachgedacht habe.

40. Beim Bewältigen von Aufgaben bevorzuge ich es

- ◯ einen Lösungsweg zu perfektionieren.
- ◯ mir neue Lösungswege einfallen zu lassen.

41. Wenn mir statistische Daten gezeigt werden, bevorzuge ich

- ◯ Diagramme und Graphen.
- ◯ eine textliche Zusammenfassung der Ergebnisse.

42. Wenn ich einen wissenschaftlichen Artikel schreibe,

- ◯ arbeite ich mich (gedanklich oder schriftlich) eher vom Beginn des Artikels zum Ende hin durch.
- ◯ arbeite ich (gedanklich oder schriftlich) an verschiedenen Kapiteln des Artikels und ordne sie erst anschließend.

43. Wenn ich an einer Gruppenarbeit teilnehme, finde ich es am besten,

- ◯ wenn man mit einer Brainstorming-Runde beginnt, in der jeder seine Ideen vorbringt.
- ◯ wenn zuerst jeder für sich Ideen sammelt, die dann in der Gruppe besprochen werden.

44. Ich halte es für ein größeres Kompliment, jemanden als

- ◯ vernünftig zu bezeichnen.
- ◯ phantasievoll zu bezeichnen.

45. Wenn ich Menschen auf einer Party kennen lerne, erinnere ich mich eher daran,

- ◯ wie sie aussahen.
- ◯ was sie von sich erzählt haben.

46. Wenn ich mich in ein neues Fachgebiet einarbeite,

- ◯ konzentriere ich mich ganz auf dieses Fach und lerne so viel ich kann.
- ◯ versuche ich Verbindungen zu anderen Fächern herzustellen.

47. Ich gelte eher als

- ◯ kontaktfreudig.
- ◯ zurückhaltend.

48. Ich bevorzuge Kurse,

- ◯ die ihren Schwerpunkt auf konkrete Anwendungen, Daten und Fakten legen.
- ◯ die abstrakte Konzepte und Theorien in den Vordergrund stellen.

49. Zur Unterhaltung

- ◯ schaue ich lieber fern.
- ◯ lese ich lieber ein Buch.

50. Einige Dozenten beginnen Ihre Vorlesungen mit einer Zusammenfassung des zu behandelnden Stoffes. Solche Zusammenfassungen sind für mich

- ◯ ein Stück weit hilfreich.
- ◯ sehr hilfreich.

51. Der Gedanke an eine Gruppenhausaufgabe, die gemeinsam benotet wird

- ◯ gefällt mir.
- ◯ gefällt mir nicht.

52. Wenn ich lange Berechnungen durchführe,

- ◯ tendiere ich dazu, alle meine Schritte erneut durchzugehen und meine Arbeit genau zu überprüfen.
- ◯ finde ich das Überprüfen meiner Arbeit ermüdend und muss mich dazu zwingen.

53. Mir einen Ort vorzustellen, an dem ich schon einmal war, ist für mich

- ◯ einfach und ziemlich präzise.
- ◯ schwierig und arm an Details.

54. Wenn ich mit einer Gruppe an der Lösung eines Problems arbeite,

- ◯ denke ich eher die Schritte des Lösungsweges durch.
- ◯ denke ich eher an mögliche Konsequenzen oder Anwendungsmöglichkeiten der Lösung in anderen Feldern.

Seite 10

Demographie

Zum Abschluss haben wir noch ein paar demographische Fragen für dich und brauchen zur Pseudonymisierung des Fragebogens noch deine Codenummer.

Hinweis: Die Daten gehen direkt an den Forscher und können nicht mit Immatrikulationsdaten abgeglichen werden.

55. Wie alt bist du?

[ ]

56. Bist du

- ◯ männlich
- ◯ weiblich
- ◯ [ ]

57. Was ist dein bisher höchster Bildungsabschluss?

- ◯ Abitur
- ◯ Bachelor
- ◯ Master
- ◯ [ ]

58. Was studierst du?

- ◯ Bachelor Informatik
- ◯ Master Informatik
- ◯ [ ]

59. Hast du die Veranstaltung, in der die Studie durchgeführt wird, in einem früheren Semester schon einmal besucht?

- ◯ ja
- ◯ nein

60. Hattest du in der Schule Informatikunterricht?

- ◯ gar nicht
- ◯ in der Mittelstufe
- ◯ als Grundkurs
- ◯ als Leistungskurs
- ◯ [ ]

61. Da wir dich mehrmals befragen wollen, brauchen wir eine Codenummer, um die Bögen zuzuordnen. Dies ist notwendig, damit die Befragung anonym durchgeführt werden kann.

Bitte erstelle diese Codenummer jetzt, indem du die Kästchen ausfüllst.

Der erste Buchstabe des Vornamens deiner Mutter:	[ ]
Der zweite Buchstabe der Straße, in der du wohnst:	[ ]
Der dritte Buchstabe deines Nachnamens:	[ ]
Die erste Ziffer deiner Hausnummer:	[ ]

Vielen Dank für deine Teilnahme!

Wir möchten uns ganz herzlich für deine Mithilfe bedanken.

Alle weiteren Informationen findest du im Moodle-Kurs unter: http://typo.service.tu-berlin.de Bei Fragen schreibe gerne an arno.wilhelm-weidnertu-berlin.de

Deine Antworten wurden gespeichert, du kannst das Browser-Fenster nun schließen.

M.Sc. Arno Wilhelm-Weidner, Technische Universität Berlin – 2017

E.2 Second Questionnaire

Seite 01

Herzlich willkommen! In dieser zweiten Befragung soll es darum gehen, mehr darüber zu erfahren, wie du lernst und wie dein Vorwissen zum behandelten Stoff der nächsten Wochen ist.

Die Umfrage dauert ungefähr 10 Minuten.

Bitte beantworte die Fragen wahrheitsgemäß, um ein möglichst aussagekräftiges Ergebnis der Studie zu ermöglichen.

Wenn du bei inhaltlichen Fragen die Lösung nicht weißt, gibt es dafür immer eine explizite Option.
Bitte nicht raten.

Sämtliche Daten werden anonymisiert erhoben und ausschließlich zu Forschungszwecken verwendet.

Die Antworten haben keinerlei Auswirkung auf deine Bewertung in der Veranstaltung.

Vielen Dank, dass du dir die Zeit nimmst!
Arno

Seite 02

FAM ansehen

Auf dieser Seite siehst du einige Fragen zu deinem Wissen rund um die Veranstaltung 'Reaktive Systeme'. Du bekommst die Aufgaben auf dieser Seite später erneut und wirst dann gebeten sie zu beantworten.
Lies dir nun erstmal die folgenden vier Aufgaben in Ruhe durch und überlege dir, wie du sie lösen würdest.

Gegeben sei eine monotone Funktion $f : D \to D$ und ein vollständiger Verband $(D, \leq)$ mit $D \triangleq \{x \in \mathbb{N} | x < 3\}$.

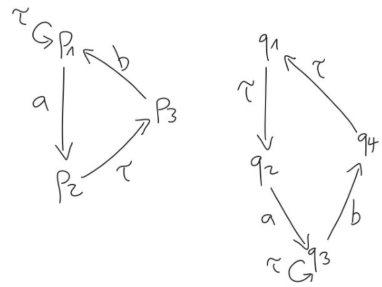
Was ist der größte Fixpunkt von f für ein passendes m aus den natürlichen Zahlen?

Welche der folgenden Formeln beschreibt **nicht** Monotonie?

- $\forall d \in D. \forall d' \in D. d \sqsubseteq d' \to f(d) \sqsubseteq f(d')$
- $\forall d \in D. \forall d' \in D. \neg(d \sqsubseteq d') \vee f(d) \sqsubseteq f(d')$
- $\forall d \in D. d \sqsubseteq f(d)$

Angenommen ein Prozess p_1 wird stark von einem anderen Prozess p_2 simuliert.
Welche Äquivalenzen gelten dann noch?

Gegeben sei das folgende LTS:



Was ist eine passende Bisimulationsrelation um zu zeigen, dass $p_1 \approx q_1$?

- $\{(p_1, q_1), (p_1, q_2), (p_2, q_3), (p_3, q_3), (p_1, q_4)\}$
- $\{(p_1, q_1), (p_1, q_2), (p_1, q_3), (p_2, q_3), (p_3, q_3), (p_1, q_4)\}$
- $\{(p_1, q_1), (p_1, q_2), (p_2, q_3), (p_1, q_4)\}$
- Es gibt keine solche Relation.

Nun wollen wir wissen, wie deine momentane Einstellung zu den beschriebenen Aufgaben ist. Dazu findest du auf dieser Seite Aussagen. Markiere bitte das Feld, das auf dich am Besten passt.

	Trifft nicht zu						Trifft zu
Ich mag solche Rätsel und Knobeleien.	○	○	○	○	○	○	○
Ich glaube, der Schwierigkeit dieser Aufgaben gewachsen zu sein.	○	○	○	○	○	○	○
Wahrscheinlich werde ich die Aufgaben nicht schaffen.	○	○	○	○	○	○	○
Bei den Aufgaben mag ich die Rolle des Wissenschaftlers, der Zusammenhänge entdeckt.	○	○	○	○	○	○	○
Ich fühle mich unter Druck, bei den Aufgaben gut abschneiden zu müssen.	○	○	○	○	○	○	○
Die Aufgaben sind eine richtige Herausforderung für mich.	○	○	○	○	○	○	○
Nach dem Lesen der Instruktion erscheinen mir die Aufgaben sehr interessant.	○	○	○	○	○	○	○
Ich bin sehr gespannt darauf, wie gut ich hier abschneiden werde.	○	○	○	○	○	○	○
Ich fürchte mich ein wenig davor, dass ich mich hier blamieren könnte.	○	○	○	○	○	○	○
Ich bin fest entschlossen, mich bei diesen Aufgaben voll anzustrengen.	○	○	○	○	○	○	○
Bei Aufgaben wie diesen brauche ich keine Belohnung, sie machen mir auch so viel Spaß.	○	○	○	○	○	○	○
Es ist mir etwas peinlich, hier zu versagen.	○	○	○	○	○	○	○
Ich glaube, das kann jeder schaffen.	○	○	○	○	○	○	○
Ich glaube, ich schaffe diese Aufgaben nicht.	○	○	○	○	○	○	○
Wenn ich die Aufgaben schaffe, werde ich schon ein wenig stolz auf meine Tüchtigkeit sein.	○	○	○	○	○	○	○
Wenn ich an die Aufgaben denke, bin ich etwas beunruhigt.	○	○	○	○	○	○	○
Solche Aufgaben würde ich auch in meiner Freizeit bearbeiten.	○	○	○	○	○	○	○
Die konkreten Leistungsanforderungen hier lähmen mich.	○	○	○	○	○	○	○

Als nächstes würden wir gern etwas über deinen Wissensstand zu bestimmten Bereichen erfahren, egal ob sie bereits Teil des Studiums waren oder noch nicht.

Hinweis: Bei einer der Fragen sind auch Mehrfachantworten möglich.

	weiß ich gar nichts darüber … kann ich sehr gut
Calculus of Communicating Systems (CCS)	
Starke und schwache Bisimulation	
partielle Ordnungen und Verbände	
Fixpunkte	
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1. Gegeben sei eine monotone Funktion $f : D \to D$ und ein vollständiger Verband $(D, \leq)$ mit $D \triangleq \{x \in \mathbb{N} | x < 3\}$.

   Was ist der größte Fixpunkt von f für ein passendes m aus den natürlichen Zahlen?

○ $f^m(4)$
○ $f^m(3)$
○ $f^m(2)$
○ $f^m(0)$

○ weiß nicht

2. Welche der folgenden Formeln beschreibt **nicht** Monotonie?

○ $\forall d \in D. \forall d' \in D. d \sqsubseteq d' \to f(d) \sqsubseteq f(d')$
○ $\forall d \in D. \forall d' \in D. \neg(d \sqsubseteq d') \vee f(d) \sqsubseteq f(d')$
○ $\forall d \in D. d \sqsubseteq f(d)$

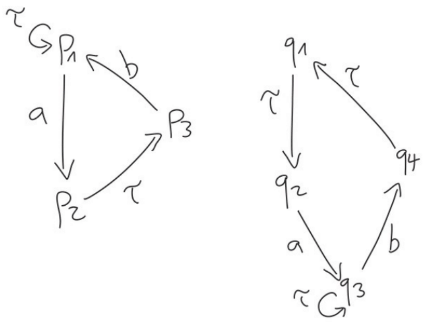
○ weiß nicht

3. Angenommen ein Prozess p_1 wird stark von einem anderen Prozess p_2 simuliert. Welche Äquivalenzen gelten dann noch?

☐ p_2 wird stark von p_1 simuliert
☐ p_1 wird schwach von p_2 simuliert
☐ $Traces(p_1) = Traces(p_2)$

☐ weiß nicht

4. Gegeben sei das folgende LTS:

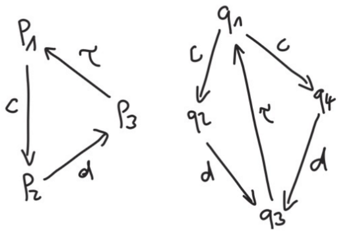


Was ist eine passende Bisimulationsrelation um zu zeigen, dass $p_1 \approx q_1$?

- ◯ $\{(p_1, q_1), (p_1, q_2), (p_2, q_3), (p_3, q_3), (p_1, q_4)\}$
- ◯ $\{(p_1, q_1), (p_1, q_2), (p_1, q_3), (p_2, q_3), (p_3, q_3), (p_1, q_4)\}$
- ◯ $\{(p_1, q_1), (p_1, q_2), (p_2, q_3), (p_1, q_4)\}$
- ◯ Es gibt keine solche Relation.

- ◯ weiß nicht

5. Gegeben sei das folgende LTS:

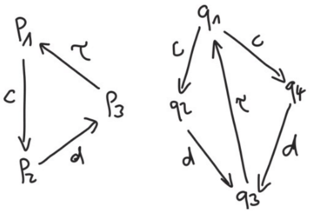


- Sind p_3 und q_3 stark bisimilar?

◯ ja
◯ nein

◯ weiß nicht

6. Gegeben sei das folgende LTS:



- Ist $\{(p_1, q_1), (p_2, q_2), (p_3, q_3)\}$ eine passende Bisimulationsrelation um zu zeigen, dass $p_1 \sim q_1$ gilt?

◯ ja
◯ nein

◯ weiß nicht

Gegeben sei ein beliebiges LTS. Ist die leere Menge hier eine Bisimulation?

◯ ja
◯ nein

◯ weiß nicht

7. Angenommen X ist eine Bisimulation. Ist X^{-1} dann ebenfalls eine Bisimulation?

◯ ja
◯ nein

◯ weiß nicht

8. Angenommen X und Y sind Bisimulationen. Ist $X \cap Y$ dann ebenfalls eine Bisimulation?

- ◯ ja
- ◯ nein

- ◯ weiß nicht

9. Angenommen X und Y sind Bisimulationen. Ist $X \cup Y$ dann ebenfalls eine Bisimulation?

- ◯ ja
- ◯ nein

- ◯ weiß nicht

Seite 06

10. Hattest du Zugriff auf die Lerneinheit zur Bisimulation?

- ◯ ja
- ◯ nein

Seite 07

UEQ

PHP-Code

```
if (value('FI02') == 1) {
  question('UE01','number=no');
} else {
  goToPage('Code');
}
```

question('UE01', 'number=no')

Um die Lerneinheiten, die du auf Moodle benutzen konntest, zu bewerten, fülle bitte den nachfolgenden Fragebogen aus. Er besteht aus Gegensatzpaaren von Eigenschaften, die die Lerneinheit haben kann. Abstufungen zwischen den Gegensätzen sind durch Kreise dargestellt. Durch Ankreuzen eines dieser Kreise kannst du deine Zustimmung zu einem Begriff äußern.

Entscheide möglichst spontan. Es ist wichtig, dass du nicht lange über die Begriffe nachdenkst, damit deine unmittelbare Einschätzung zum Tragen kommt.

Bitte kreuze immer eine Antwort an, auch wenn du bei der Einschätzung zu einem Begriffspaar unsicher bist oder findest, dass es nicht so gut zur Lerneinheit passt.

Es gibt keine „richtige“ oder „falsche“ Antwort. Deine persönliche Meinung zählt!

unerfreulich	○ ○ ○ ○ ○ ○ ○	erfreulich
unverständlich	○ ○ ○ ○ ○ ○ ○	verständlich
kreativ	○ ○ ○ ○ ○ ○ ○	phantasielos
leicht zu lernen	○ ○ ○ ○ ○ ○ ○	schwer zu lernen
wertvoll	○ ○ ○ ○ ○ ○ ○	minderwertig
langweilig	○ ○ ○ ○ ○ ○ ○	spannend
uninteressant	○ ○ ○ ○ ○ ○ ○	interessant
unberechenbar	○ ○ ○ ○ ○ ○ ○	voraussagbar
schnell	○ ○ ○ ○ ○ ○ ○	langsam
originell	○ ○ ○ ○ ○ ○ ○	konventionell
behindernd	○ ○ ○ ○ ○ ○ ○	unterstützend
gut	○ ○ ○ ○ ○ ○ ○	schlecht
kompliziert	○ ○ ○ ○ ○ ○ ○	einfach
abstoßend	○ ○ ○ ○ ○ ○ ○	anziehend
herkömmlich	○ ○ ○ ○ ○ ○ ○	neuartig
unangenehm	○ ○ ○ ○ ○ ○ ○	angenehm
sicher	○ ○ ○ ○ ○ ○ ○	unsicher
aktivierend	○ ○ ○ ○ ○ ○ ○	einschläfernd
erwartungskonform	○ ○ ○ ○ ○ ○ ○	nicht erwartungskonform
ineffizient	○ ○ ○ ○ ○ ○ ○	effizient
übersichtlich	○ ○ ○ ○ ○ ○ ○	verwirrend
unpragmatisch	○ ○ ○ ○ ○ ○ ○	pragmatisch
aufgeräumt	○ ○ ○ ○ ○ ○ ○	überladen
attraktiv	○ ○ ○ ○ ○ ○ ○	unattraktiv
sympathisch	○ ○ ○ ○ ○ ○ ○	unsympathisch
konservativ	○ ○ ○ ○ ○ ○ ○	innovativ

Im Folgenden wollen wir noch ein bisschen mehr darüber erfahren, wie dir die Lerneinheiten gefallen haben und wie man sie verbessern könnte.

	sehr einfach	sehr umständlich
Wie war die Bedienung der Lerneinheiten allgemein für dich?		

	Text	Video
Welche Art von Erklärungen hast du bei den Lerneinheiten häufiger benutzt?		

	< 1 Stunde	1-5 Stunden	5 – 10 Stunden	> 10 Stunden
Wie lang hast du dich insgesamt mit den Lerneinheiten beschäftigt?	◯	◯	◯	◯

Welche Schwierigkeiten bei der Bedienung traten auf?

Was sollte an den Lerneinheiten verbessert werden?

11. Da wir dich mehrmals befragen wollen, brauchen wir eine Codenummer, um die Bögen zuzuordnen. Dies ist notwendig, damit die Befragung anonym durchgeführt werden kann.

Bitte erstelle diese Codenummer jetzt, indem du die Kästchen ausfüllst.

Der erste Buchstabe des Vornamens deiner Mutter:	
Der zweite Buchstabe der Straße, in der du wohnst:	
Der dritte Buchstabe deines Nachnamens:	
Die erste Ziffer deiner Hausnummer:	

Letzte Seite

Vielen Dank für deine Teilnahme!

Wir möchten uns ganz herzlich für deine Mithilfe bedanken.

Bei Fragen schreibe gerne an arno.wilhelm-weidner@tu-berlin.de

Deine Antworten wurden gespeichert, du kannst das Browser-Fenster nun schließen.

M.Sc. Arno Wilhelm-Weidner, Technische Universität Berlin – 2017

E.3 Third Questionnaire

Seite 01

Herzlich willkommen! In dieser dritten Befragung soll es darum gehen, mehr darüber zu erfahren, was du in den vergangenen Wochen gelernt hast und wie dein Verhältnis dazu ist.

Die Umfrage dauert ungefähr 10 Minuten.

Bitte beantworte die Fragen wahrheitsgemäß, um ein möglichst aussagekräftiges Ergebnis der Studie zu ermöglichen.

Wenn du bei inhaltlichen Fragen die Lösung nicht weißt, gibt es dafür immer eine explizite Option.
Bitte nicht raten.

Sämtliche Daten werden anonymisiert erhoben und ausschließlich zu Forschungszwecken verwendet.

Die Antworten haben keinerlei Auswirkung auf deine Bewertung in der Veranstaltung.

Vielen Dank, dass du dir die Zeit nimmst!
Arno

Seite 02

FAM ansehen

Auf dieser Seite siehst du einige Fragen zu deinem Wissen rund um die Veranstaltung 'Reaktive Systeme (ReSyst)'. Du bekommst die Aufgaben auf dieser Seite später erneut und wirst dann gebeten sie zu beantworten.
Lies dir nun erstmal die folgenden vier Aufgaben in Ruhe durch und überlege dir, wie du sie lösen würdest.

Gegeben sei eine monotone Funktion $f : D \to D$ und ein vollständiger Verband $(D, \sqsubseteq)$ mit $D \triangleq 2^{2^A}$ für eine endliche Menge A.

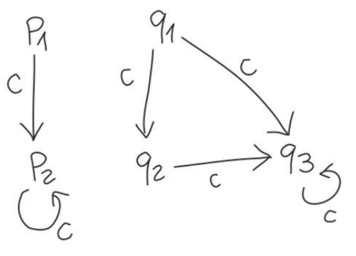
Was ist der größte Fixpunkt von f für ein passendes m aus den natürlichen Zahlen?

Welche der folgenden Formeln beschreibt Monotonie?

- $\forall d \in D. \forall d' \in D. d \sqsubseteq d' \to f(d) \sqsubseteq f(d')$
- $\forall d \in D. \forall d' \in D. d \sqsubseteq f(d) \to d' \sqsubseteq f(d')$
- $\forall d \in D. \forall d' \in D. f(d) \sqsubseteq f(d') \to d \sqsubseteq d'$

Angenommen ein Prozess p_1 ist schwach bisimilar zu einem anderen Prozess p_2. Welche Äquivalenzen gelten dann noch?

Gegeben sei das folgende LTS:



Was ist eine passende Bisimulationsrelation um zu zeigen, dass $p_1 \sim q_1$?

- $\{p_1, q_1\}$
- $\{(p_1, q_1), (p_2, q_3)\}$
- $\{p_2, q_2, q_3\}$
- $\{(p_1, q_1), (p_2, q_2), (p_2, q_3)\}$

Nun wollen wir wissen, wie deine momentane Einstellung zu den beschriebenen Aufgaben ist. Dazu findest du auf dieser Seite Aussagen. Markiere bitte das Feld, das auf dich am Besten passt.

	Trifft nicht zu						Trifft zu
Ich mag solche Rätsel und Knobeleien.	○	○	○	○	○	○	○
Ich glaube, der Schwierigkeit dieser Aufgaben gewachsen zu sein.	○	○	○	○	○	○	○
Wahrscheinlich werde ich die Aufgaben nicht schaffen.	○	○	○	○	○	○	○
Bei den Aufgaben mag ich die Rolle des Wissenschaftlers, der Zusammenhänge entdeckt.	○	○	○	○	○	○	○
Ich fühle mich unter Druck, bei den Aufgaben gut abschneiden zu müssen.	○	○	○	○	○	○	○
Die Aufgaben sind eine richtige Herausforderung für mich.	○	○	○	○	○	○	○
Nach dem Lesen der Instruktion erscheinen mir die Aufgaben sehr interessant.	○	○	○	○	○	○	○
Ich bin sehr gespannt darauf, wie gut ich hier abschneiden werde.	○	○	○	○	○	○	○
Ich fürchte mich ein wenig davor, dass ich mich hier blamieren könnte.	○	○	○	○	○	○	○
Ich bin fest entschlossen, mich bei diesen Aufgaben voll anzustrengen.	○	○	○	○	○	○	○
Bei Aufgaben wie diesen brauche ich keine Belohnung, sie machen mir auch so viel Spaß.	○	○	○	○	○	○	○
Es ist mir etwas peinlich, hier zu versagen.	○	○	○	○	○	○	○
Ich glaube, das kann jeder schaffen.	○	○	○	○	○	○	○
Ich glaube, ich schaffe diese Aufgaben nicht.	○	○	○	○	○	○	○
Wenn ich die Aufgaben schaffe, werde ich schon ein wenig stolz auf meine Tüchtigkeit sein.	○	○	○	○	○	○	○
Wenn ich an die Aufgaben denke, bin ich etwas beunruhigt.	○	○	○	○	○	○	○
Solche Aufgaben würde ich auch in meiner Freizeit bearbeiten.	○	○	○	○	○	○	○
Die konkreten Leistungsanforderungen hier lähmen mich.	○	○	○	○	○	○	○

Als nächstes würden wir gern etwas über deinen Wissensstand zu bestimmten Bereichen erfahren, egal ob sie bereits Teil des Studiums waren oder noch nicht.

Hinweis: Bei einer der Fragen sind auch Mehrfachantworten möglich.

	weiß ich gar nichts darüber … kann ich sehr gut
Calculus of Communicating Systems (CCS)	
Starke und schwache Bisimulation	
partielle Ordnungen und Verbände	
Fixpunkte	
Berechnung von Fixpunkten auf Verbänden	

Gegeben sei eine monotone Funktion $f : D \to D$ und ein vollständiger Verband $(D, \sqsubseteq)$ mit $D \triangleq 2^{2^A}$ für eine endliche Menge A.

Was ist der größte Fixpunkt von f für ein passendes m aus den natürlichen Zahlen?

- ○ $f^m(A)$
- ○ $f^m(A \times A)$
- ○ $f^m(2^A)$
- ○ $f^m(2^{A \times A})$

- ○ weiß nicht

Welche der folgenden Formeln beschreibt Monotonie?

- ○ $\forall d \in D. \forall d' \in D. d \sqsubseteq d' \to f(d) \sqsubseteq f(d')$
- ○ $\forall d \in D. \forall d' \in D. d \sqsubseteq f(d) \to d' \sqsubseteq f(d')$
- ○ $\forall d \in D. \forall d' \in D. f(d) \sqsubseteq f(d') \to d \sqsubseteq d'$

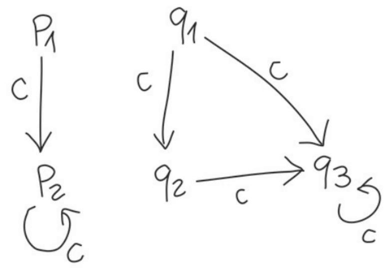
- ○ weiß nicht

Angenommen ein Prozess p_1 ist schwach bisimilar zu einem anderen Prozess p_2. Welche Äquivalenzen gelten dann noch?

- ☐ $p_2 \sim p_1$
- ☐ $p_1 \approx p_2$
- ☐ $Traces(p_1) = Traces(p_2)$

- ☐ weiß nicht

Gegeben sei das folgende LTS:



Was ist eine passende Bisimulationsrelation um zu zeigen, dass $p_1 \sim q_1$?

- ○ $\{p_1, q_1\}$
- ○ $\{(p_1, q_1), (p_2, q_3)\}$
- ○ $\{p_2, q_2, q_3\}$
- ○ $\{(p_1, q_1), (p_2, q_2), (p_2, q_3)\}$

- ○ weiß nicht

Seite 05

Was berechnet $\mathcal{F}^M(\emptyset)$ für ein passendes $M \in \mathbb{N}$?

- ○ kleinster Fixpunkt
- ○ kleinste Bisimulation
- ○ beides

- ○ weiß nicht

Welche der folgenden Punkte sind Voraussetzungen zur Berechnung von Fixpunkten der Funktion $g : E \to E$ auf dem Verband $M = (E, \sqsubseteq)$ mit dem Knaster-Tarski-Theorem?

- ☐ M ist ein vollständiger Verband
- ☐ M ist ein endlicher Verband
- ☐ $\sqsubseteq$ ist eine reflexive Relation
- ☐ g ist eine monotone Funktion
- ☐ $\sqsubseteq$ ist eine lineare Relation

- ☐ weiß nicht

Angenommen wir haben eine partielle Ordnung $(D, \sqsubseteq)$. Was muss gelten, damit es ein Verband ist?

- ○ für jedes Paar von Elementen aus D existieren Infimum und Supremum
- ○ für ein Paar von Elementen aus D existieren Infimum und Supremum

---

- ○ weiß nicht

Gegeben sei der Verband $(2^{\{a,b,f\}}, \subseteq)$ und eine Funktion $f : 2^{\{a,b,f\}} \to 2^{\{a,b,f\}}$ mit $x \mapsto x \cup \{f\}$.

Wie berechnen wir hier den größten Fixpunkt für ein passendes m?

- ◯ $f^m(2^{\{a,b,f\}})$
- ◯ $f^m(\{a,b,f\})$
- ◯ $f^m(\emptyset)$

- ◯ weiß nicht

Gegeben sei der Verband $(2^{\{a,b,f\}}, \subseteq)$ und eine Funktion $f : 2^{\{a,b,f\}} \to 2^{\{a,b,f\}}$ mit $x \mapsto x \cup \{f\}$.

Wir wollen den größten Fixpunkt berechnen. Was ist das Ergebnis nach der ersten Iteration?

- ◯ $\{f\}$
- ◯ $\{a,b,f\}$
- ◯ $\{a,b\}$
- ◯ $\{\}$

- ◯ weiß nicht

Seite 06

Hattest du Zugriff auf die Lerneinheit zur Fixpunkttheorie?

- ◯ ja
- ◯ nein

Seite 07

UEQ

PHP-Code

```
if (value('FI01') == 1) {
  question('UE01','number=no');
} else {
  goToPage('Code');
}
```

question('UE01', 'number=no')

Um die Lerneinheiten, die du auf Moodle benutzen konntest, zu bewerten, fülle bitte den nachfolgenden Fragebogen aus. Er besteht aus Gegensatzpaaren von Eigenschaften, die die Lerneinheit haben kann. Abstufungen zwischen den Gegensätzen sind durch Kreise dargestellt. Durch Ankreuzen eines dieser Kreise kannst du deine Zustimmung zu einem Begriff äußern.

Entscheide möglichst spontan. Es ist wichtig, dass du nicht lange über die Begriffe nachdenkst, damit deine unmittelbare Einschätzung zum Tragen kommt.

Bitte kreuze immer eine Antwort an, auch wenn du bei der Einschätzung zu einem Begriffspaar unsicher bist oder findest, dass es nicht so gut zur Lerneinheit passt.

Es gibt keine „richtige“ oder „falsche“ Antwort. Deine persönliche Meinung zählt!

unerfreulich	○ ○ ○ ○ ○ ○ ○	erfreulich
unverständlich	○ ○ ○ ○ ○ ○ ○	verständlich
kreativ	○ ○ ○ ○ ○ ○ ○	phantasielos
leicht zu lernen	○ ○ ○ ○ ○ ○ ○	schwer zu lernen
wertvoll	○ ○ ○ ○ ○ ○ ○	minderwertig
langweilig	○ ○ ○ ○ ○ ○ ○	spannend
uninteressant	○ ○ ○ ○ ○ ○ ○	interessant
unberechenbar	○ ○ ○ ○ ○ ○ ○	voraussagbar
schnell	○ ○ ○ ○ ○ ○ ○	langsam
originell	○ ○ ○ ○ ○ ○ ○	konventionell
behindernd	○ ○ ○ ○ ○ ○ ○	unterstützend
gut	○ ○ ○ ○ ○ ○ ○	schlecht
kompliziert	○ ○ ○ ○ ○ ○ ○	einfach
abstoßend	○ ○ ○ ○ ○ ○ ○	anziehend
herkömmlich	○ ○ ○ ○ ○ ○ ○	neuartig
unangenehm	○ ○ ○ ○ ○ ○ ○	angenehm
sicher	○ ○ ○ ○ ○ ○ ○	unsicher
aktivierend	○ ○ ○ ○ ○ ○ ○	einschläfernd
erwartungskonform	○ ○ ○ ○ ○ ○ ○	nicht erwartungskonform
ineffizient	○ ○ ○ ○ ○ ○ ○	effizient
übersichtlich	○ ○ ○ ○ ○ ○ ○	verwirrend
unpragmatisch	○ ○ ○ ○ ○ ○ ○	pragmatisch
aufgeräumt	○ ○ ○ ○ ○ ○ ○	überladen
attraktiv	○ ○ ○ ○ ○ ○ ○	unattraktiv
sympathisch	○ ○ ○ ○ ○ ○ ○	unsympathisch
konservativ	○ ○ ○ ○ ○ ○ ○	innovativ

Im Folgenden wollen wir noch ein bisschen mehr darüber erfahren, wie dir die Lerneinheiten gefallen haben und wie man sie verbessern könnte.

	sehr einfach	sehr umständlich
Wie war die Bedienung der Lerneinheiten allgemein für dich?		

	Text	Video
Welche Art von Erklärungen hast du bei den Lerneinheiten häufiger benutzt?		

	< 1 Stunde	1-5 Stunden	5 – 10 Stunden	> 10 Stunden
Wie lang hast du dich insgesamt mit den Lerneinheiten beschäftigt?	◯	◯	◯	◯

Welche Schwierigkeiten bei der Bedienung traten auf?

Was sollte an den Lerneinheiten verbessert werden?

---

1. Da wir dich mehrmals befragen wollen, brauchen wir eine Codenummer, um die Bögen zuzuordnen. Dies ist notwendig, damit die Befragung anonym durchgeführt werden kann.

Bitte erstelle diese Codenummer jetzt, indem du die Kästchen ausfüllst.

Der erste Buchstabe des Vornamens deiner Mutter:	
Der zweite Buchstabe der Straße, in der du wohnst:	
Der dritte Buchstabe deines Nachnamens:	
Die erste Ziffer deiner Hausnummer:	

2. Möchtest du an der Verlosung um den 25 € Amazon-Gutschein teilnehmen?

◯ ja

◯ nein

Vielen Dank für deine Teilnahme!

Wir möchten uns ganz herzlich für deine Mithilfe bedanken.

Alle weiteren Informationen findest du im Moodle-Kurs unter: http://typo.service.tu-berlin.de
Bei Fragen schreibe gerne an arno.wilhelm-weidner@tu-berlin.de

Deine Antworten wurden gespeichert, du kannst das Browser-Fenster nun schließen.

M.Sc. Arno Wilhelm-Weidner, Technische Universität Berlin – 2017

E.4 Follow-Up Questionnaire

Seite 01

Herzlich Willkommen!

Zum Abschluss wollen wir dir noch ein paar kurze Fragen zur Nutzung der Lerneinheit und zu deinem Abschneiden im Modul stellen. Die Befragung ist pseudonymisiert, die Daten gehen direkt an den Forscher und werden ausschließlich zu Forschungszwecken verwendet.

Danke für deine Teilnahme!

Um die Lerneinheiten, die du auf Moodle benutzen konntest, zu bewerten, fülle bitte den nachfolgenden Fragebogen aus. Er besteht aus Gegensatzpaaren von Eigenschaften, die die Lerneinheit haben kann. Abstufungen zwischen den Gegensätzen sind durch Kreise dargestellt. Durch Ankreuzen eines dieser Kreise kannst du deine Zustimmung zu einem Begriff äußern.

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Es gibt keine „richtige“ oder „falsche“ Antwort. Deine persönliche Meinung zählt!

unerfreulich	○ ○ ○ ○ ○ ○ ○	erfreulich
unverständlich	○ ○ ○ ○ ○ ○ ○	verständlich
kreativ	○ ○ ○ ○ ○ ○ ○	phantasielos
leicht zu lernen	○ ○ ○ ○ ○ ○ ○	schwer zu lernen
wertvoll	○ ○ ○ ○ ○ ○ ○	minderwertig
langweilig	○ ○ ○ ○ ○ ○ ○	spannend
uninteressant	○ ○ ○ ○ ○ ○ ○	interessant
unberechenbar	○ ○ ○ ○ ○ ○ ○	voraussagbar
schnell	○ ○ ○ ○ ○ ○ ○	langsam
originell	○ ○ ○ ○ ○ ○ ○	konventionell
behindernd	○ ○ ○ ○ ○ ○ ○	unterstützend
gut	○ ○ ○ ○ ○ ○ ○	schlecht
kompliziert	○ ○ ○ ○ ○ ○ ○	einfach
abstoßend	○ ○ ○ ○ ○ ○ ○	anziehend
herkömmlich	○ ○ ○ ○ ○ ○ ○	neuartig
unangenehm	○ ○ ○ ○ ○ ○ ○	angenehm
sicher	○ ○ ○ ○ ○ ○ ○	unsicher
aktivierend	○ ○ ○ ○ ○ ○ ○	einschläfernd
erwartungskonform	○ ○ ○ ○ ○ ○ ○	nicht erwartungskonform
ineffizient	○ ○ ○ ○ ○ ○ ○	effizient
übersichtlich	○ ○ ○ ○ ○ ○ ○	verwirrend
unpragmatisch	○ ○ ○ ○ ○ ○ ○	pragmatisch
aufgeräumt	○ ○ ○ ○ ○ ○ ○	überladen
attraktiv	○ ○ ○ ○ ○ ○ ○	unattraktiv

sympathisch	○ ○ ○ ○ ○ ○ ○	unsympathisch
konservativ	○ ○ ○ ○ ○ ○ ○	innovativ

Seite 03

Im Folgenden wollen wir noch ein bisschen mehr darüber erfahren, wie dir die Lerneinheiten gefallen haben und wie man sie verbessern könnte.

	sehr einfach	sehr umständlich
Wie war die Bedienung der Lerneinheiten allgemein für dich?		

Welche Schwierigkeiten bei der Bedienung traten auf?

Was sollte an den Lerneinheiten verbessert werden?

	< 1 Stunde	1-5 Stunden	5 – 10 Stunden	> 10 Stunden
Wie lang hast du dich insgesamt mit den Lerneinheiten beschäftigt?	○	○	○	○

	Text	Video
Welche Art von Erklärungen hast du bei den Lerneinheiten häufiger benutzt?		

Seite 04

Welche Note hast du im Sommersemester 2018 im Modul ‚Reaktive Systeme' erreicht?

- ◯ 1,0 – 1,3
- ◯ 1,7 – 2,0
- ◯ 2,3 – 2,7
- ◯ 3,0 – 3,3
- ◯ 3,7 – 4,0
- ◯ 5,0

- ◯ möchte ich nicht beantworten
- ◯ weiß ich nicht

Seite 05

Da wir dich mehrmals befragen wollen, brauchen wir eine Codenummer, um die Bögen zuzuordnen. Dies ist notwendig, damit die Befragung anonym durchgeführt werden kann.

Bitte erstelle diese Codenummer jetzt, indem du die Kästchen ausfüllst.

Der erste Buchstabe des Vornamens deiner Mutter:	☐
Der zweite Buchstabe der Straße, in der du wohnst:	☐
Der dritte Buchstabe deines Nachnamens:	☐
Die erste Ziffer deiner Hausnummer:	☐

Vielen Dank für deine Teilnahme!

Wir möchten uns ganz herzlich für die Mithilfe bedanken.

Die Antworten wurden gespeichert, du kannst das Browser-Fenster nun schließen.Bei weiteren Fragen oder ähnlichem schreibe gern an arno.wilhelm-weidnertu-berlin.de

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Möchten Sie in Zukunft an interessanten und spannenden Online-Befragungen teilnehmen?

Wir würden uns sehr freuen, wenn Sie Ihre E-Mail-Adresse für das SoSci Panel anmelden und damit wissenschaftliche Forschungsprojekte unterstützen.

E-Mail: ______ Am Panel teilnehmen

Die Teilnahme am SoSci Panel ist freiwillig, unverbindlich und kann jederzeit widerrufen werden.
Das SoSci Panel speichert Ihre E-Mail-Adresse nicht ohne Ihr Einverständnis, sendet Ihnen keine Werbung und gibt Ihre E-Mail-Adresse nicht an Dritte weiter.

Sie können das Browserfenster selbstverständlich auch schließen, ohne am SoSci Panel teilzunehmen.

M.Sc. Arno Wilhelm-Weidner, Technische Universität Berlin – 2017