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Competence-based Strategies for Personalising the Learning Experience in Virtual Environments

DOCTORAL THESIS

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AFFIDAVIT

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Abstract

This doctoral thesis presents a conceptual framework and a corresponding software application that aim at enriching existing learning technologies with an approach for personalised, competence-based, and self-regulated learning. It has been recognised that new forms of learning and teaching are necessary in the educational sector, which includes meta-cognitive competences and self-regulation, competence-orientated knowledge acquisition, personalised learning, and learning in realistic environments. While learning technology is more and more pervading all kinds of educational organisations, these new kinds of learning and teaching are not sufficiently addressed by currently used technologies. This thesis aims at providing a solution to connect existing learning technologies with these forms of learning. More precisely, the main objectives of this thesis are the elaboration of (a) a new learning approach that connects competence-based learning, personalised learning, and self-regulated learning, and (b) a technical framework that allows the integration of this learning approach into existing computer-based learning environments. The objectives are realised through a conceptual framework that integrates Adaptive Educational Hypermedia, Self-regulated Learning, and Competence-based Knowledge Space Theory, in order to achieve a holistic learning approach. Furthermore, a technical framework and software application have been developed that implement the conceptual framework. To demonstrate the integration with existing computer-based learning environments, the developed software application was integrated in various applications in the field of Intelligent Tutoring Systems, Learning Management Systems, Personal Learning Environments, and Virtual Reality Learning Environments. An Evaluation of the conceptual framework and the software application has been completed, in order to proof their usefulness and acceptance in the educational sector. Results of the evaluation reveal that the participants accepted the learning approach, were successful in attaining knowledge and competences, and reacted positively to the support for metacognition through visualisation tools.

Kurzfassung

Diese Doktorarbeit präsentiert ein konzeptuelles Rahmenwerk und eine dazugehörige Softwareimplementierung, die darauf abzielen, bestehende Lerntechnologien mit Ansätzen zum personalisierten, kompetenzbasierten und selbstregulierten Lernen anzureichern. Es ist zunehmend anerkannt, dass neue Arten des Lernens und Lehrens im Bildungsbereich nötig sind, wie zum Beispiel Metakognition und Selbstregulierung, kompetenzbasierter Wissenserwerb, personalisiertes Lernen und Lernen in realistischen Umgebungen. Während Bildungseinrichtungen aller Art mehr und mehr von Lerntechnologien durchdrungen werden, werden den neuen Lernformen durch diese Lerntechnologien nicht ausreichend Rechnung getragen. Das Ziel dieser Arbeit ist die Bereitstellung einer Lösung, die diese Lernformen mit bestehenden Lerntechnologien verbinden kann. Die detaillierte Zielsetzung umfasst (a) die Ausarbeitung eines neuen Lernansatzes, der kompetenzbasiertes Lernen, selbstreguliertes Lernen und personalisiertes Lernen verbindet und (b) die Erstellung eines technischen Rahmenwerkes, das die Integration dieses Lernansatzes mit bestehenden computerbasierten Lernumgebungen ermöglicht. Diese Zielsetzung ist durch ein konzeptuelles Rahmenwerkes umgesetzt worden, das adaptive Hypermedia Konzepte, Theorien zum selbstregulierten Lernen, und die kompetenzbasierte Wissensraumtheorie vereint, um einen neuen ganzheitlichen Lernansatz zu ermöglichen. Des weiteren wurde ein technisches Rahmenwerk und eine Softwareanwendung entwickelt, die dieses konzeptuelle Rahmenwerk implementieren. Um die Integration mit bestehenden computerbasierten Lernumgebungen zu demonstrieren, wurde die Softwareanwendung im Kontext von Anwendungen im Bereich Intelligenter Tutorensystemen, Lernmanagementsystemen, Persönlichen Lernumgebungen, und Lernumgebungen in der virtuellen Realität getestet. Evaluierungen des konzeptuellen Rahmenwerkes und der Softwareanwenung wurde unternommen, um die Nützlichkeit und Akzeptanz im Bildungsbereich nachzuweisen. Das Ergebnis der Evaluierung zeigt, dass die Teilnehmer den Lernansatz angenommen haben, erfolgreich beim Wissenserwerb waren, und postitiv auf die Unterstützung zur Metakogntion durch Visualisierungstools reagierten.

Acknowledgements

Foremost, I would like to express my sincere gratitude to my Ph.D. supervisor Christian Gütl for the continuous support, inspiring ideas, valuable feedback, and patience. He always had a positive and motivating attitude towards this work. My sincere thanks also go to Dietrich Albert who provided me the opportunity to join the interdisciplinary Cognitive Science Section where all the work could take place in an international and research-driven environment.

My current and former colleagues at the Cognitive Science Section merit much appreciation. I have benefited from fruitful collaboration, discussions, and recommendations. Especially, Cord Hockemeyer, Christina Steiner, Eva Hillemann, Simone Kopeinik, Bernd Prünster, Marcel Berthold, Karin Fruhmann, Birgit Marte, and Claudia Repitsch had much influence on the completion of this thesis.

Furthermore, many thanks go to all the numerous people around the world working together with me in several research projects. Especially those who were involved in the projects iClass, MedCAP, GRAPPLE, and ROLE. I also would like to thank the European Commission for funding these projects. Also the anonymous people who reviewed my publications submitted to conferences and journals and provided valuable feedback have contributed to this work.

Additionally, I benefitted from the collaboration with Walter Neuper, as well as from students projects of Alexander Blaschitz, Andreas Schwarz, Rene Ranftl, Rudolf and Weißenbacher whose bachelor theses contributed to this work.

Last but not least I thank my relatives, friends, and all people who have supported and encouraged me to finish this thesis. Particularly, encouragements in numerous eligible and eliciting interlocutions are much appreciated.

Credits

The following figures and diagrams are extracted from publications:

- Figure 3.1 extracted from from Nwana (1990)
- Figure 3.2 extracted from from V. J. Shute and Psotka (1996)
- Figure 3.3 extracted from from De Bra et al. (2003)
- Figure 3.5 extracted from from Pirker, Lesjak, and Gütl (2017)
- Figure 4.1 extracted from from Brusilovsky (1996)
- Figure 4.2 extracted from from V. Shute and Towle (2003)
- Figure 4.3 extracted from from Zimmerman (2002)
- Figure 4.4 extracted from from Boekaerts (1999)

Contributions to this thesis came from:

- The original concept of an integrated model of Self-regulated Learning and Competence-based Knowledge Space Theory (see Chapter 5 was developed by Dietrich Albert, Christina Steiner, and Birgit Marte.
- The learning process model storing information about the learners current state (see Chapter 6 was the result of a collaboration with Simone Kopeinik.
- The evaluation of the Compod VLE (see Chapter 8) was conducted in collaboration with Eva Hillemann.

Finally, this thesis was written using an updated version of Keith Andrews' wonderful LaTeX skeleton thesis.

Contents

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List of Abbreviations

AEH Adaptive Educational Hypermedia

CbKST Competence-based Knowledge Space Theory

CAI Computer-assisted Instruction

CBA Computer-based Assessment

CSCL Computer-supported Collaborative Learning

CBT Computer-based Training

CTT Classical Test Theory

EAH Educational Adaptive Hypermedia

EduTech Educational Technologies

GBL Game-based Learning

GRAPPLE Generic Responsive Adaptive Personalized Learning Environment

iClass Intelligent Distributed Cognitive-based Open Learning Systems for Schools

INNOVRET Innovative Online Vocational Training of Renewable Energy Technologies

IRT Item Response Theory

ISAC ISAbelle for Calculations in Applied Mathematics

ITS Intelligent Tutoring System

KST Knowledge Space Theory

LA Learning Analytics

LD Learning Design

LE Learning Environment

LMS Learning Management System

LOM Learning Object Metadata

MedCAP Competence Assessment for Spinal Anaesthesia

MOOC Massive Open Online Course

OLM Open Learner Model

QTI Question & Test Interoperability

PLE Personal Learning Environment

RCD Reusable Competency Definitions

ROLE Responsive Open Learning Environments

SCORM Shareable Content Object Reference Model

SRL Self-regulated Learning

STEM Science, Technology, Engineering, and Maths

TEL Technology-enhanced Learning

VLE Virtual Learning Environment

VR Virtual Reality

WBT Web-based Training

WWW World Wide Web

UM User Model

ViWo Virtual World

VRLE Virtual Reality Learning Environment

Chapter 1

Introduction

This chapter introduces the topic of this thesis and gives a general overview it. The first section presents the reasons and background including a problem statement that justifies the presented work (Section 1.1). Then the general approach including research questions is presented that addresses the problem statement (Section 1.2). The scope and structure of the work is described in Section 1.3. Finally, the own scientific publications in conference proceedings and journals are listed and commented that build the basis for this work (Section 1.4).

1.1 Motivation and Background

Presently, a divergent situation can be observed where the learning technology widely used at educational organisations does not meet the new demands for learning and teaching on the one hand, and the research and developments on Technology-enhanced Learning (TEL) are not sufficiently adopted in the educational sector on the other hand.

In an analysis of the current situation at educational systems, Downes (2005) comes to the conclusion that *"e-learning mainly takes the form of online courses"* and that *"... the course is the basic unit of organisation"*. Furthermore, he considers Learning Management Systems (LMSs) as the dominant learning technology employed at educational organisations. LMSs mainly aim at managing and delivering content in the same way as done before the use of technology for learning. Though this analysis was done more than a decade ago, this situation still remains. For example, there are 89,862 currently active Moodle instances used worldwide and 784 are in Austria[1].

In a survey on the institutional take-up of e-learning, the answers from 249 European higher educational institutions have been analysed (Gaebel, Kupriyanova, Morais, & Colucci, 2014). The results indicate a widely adoption of e-learning. 91% answered that they use a blended learning approach and 82% offer online courses. While online courses were traditionally offered by specific distance learning institutions, they have entered the mainstream of higher education, in order to allow more flexible use of time and place for on-campus students. Working while studying is seen as the dominant motivation why students prefer online learning. Despite the widely take-up

[1] https://moodle.net/sites/ (October 2017)

of e-learning, the study concludes with scepticism regarding the innovation, because the offered e-learning approaches are still traditional in their type of teaching.

In contrast to this situation, a lot of innovative technologies and solutions have been researched and developed (see Chapter 2). For example Intelligent Tutoring Systems (ITSs) aim at adapting learning content and tasks to the goals, knowledge, preferences, and needs of the leaner. Personal Learning Environments (PLEs) provide learning environments that can be configured by the learner. Virtual Reality (VR) applications allow the learner to interactively explore learning tasks in a realistic environment. Game-based Learning (GBL) applications make the learning process playful. Despite huge amount of research activities in these fields, the impact on the educational sector is still rather poor.

In a recent NMC Report Horizon (L. Johnson et al., 2016), new developments and their potential for educational organisations are acknowledged. On the one hand, new technologies are mentioned that find their way into education, such as large screens for collaboration, mobile devices and Internet, and virtual and augmented reality. On the other hand, an emphasis is put on new concepts for learning and teaching that go beyond traditional settings. For example, critical thinking, problem-based learning, collaboration, and self-regulated learning lead to deeper learning. Inquiry-based learning and project-based learning foster connections between curriculum and real-world. This leads to new concepts that connect learning and teaching with new educational demands and new technologies. Massive Open Online Courses (MOOCs), learning analytics, personalisation, virtual reality, and maker spaces are mentioned as examples.

A report on learning in the 21st century (IEAB, 2008) highlights the demands and preferences of learners at present time. According to this report, they like to be in control of their schedules, they are group-oriented, and they like choices regarding the technology which they use in experienced and creative way and adapt it to their needs.

In order to address and harmonise the divergent situation with differences between the current use of technology in education, the research in TEL, the new demands for teaching and learning, and the impact on the learning outcomes, new approaches are needed. This thesis presents an approach that aims at enriching existing learning technology with an integrated learning approach based on competence-based and self-regulated learning. More precisely, **the main objectives of this thesis are the elaboration of (a) a new learning approach that connects competence-based learning, personalised learning, and self-regulated learning, and (b) a technical framework that allows the integration of this learning approach into existing computer-based learning environments**. The next section outlines the overall approach for this objective.

1.2 Approach and Research Questions

The overall approach to meet the objectives of this thesis (Section 1.1) consists in (a) the creation of a conceptual framework that integrates existing psychological, pedagogical, and technical TEL approaches, and (b) a technical framework that implements the new learning approach and makes it available for external Virtual Learning Environments (VLEs).

An overview of this approach is depicted in Figure 1.1. This figure puts the technical framework in the centre surrounded by the conceptual framework that consists of Adaptive Educational

Hypermedia (AEH), Self-regulated Learning (SRL), and Competence-based Knowledge Space Theory (CbKST). The software component that has implemented the technical framework and provides interfaces for the VLE is called Compod. The external VLEs are connected to Compod, in order to make use of its learning support features.

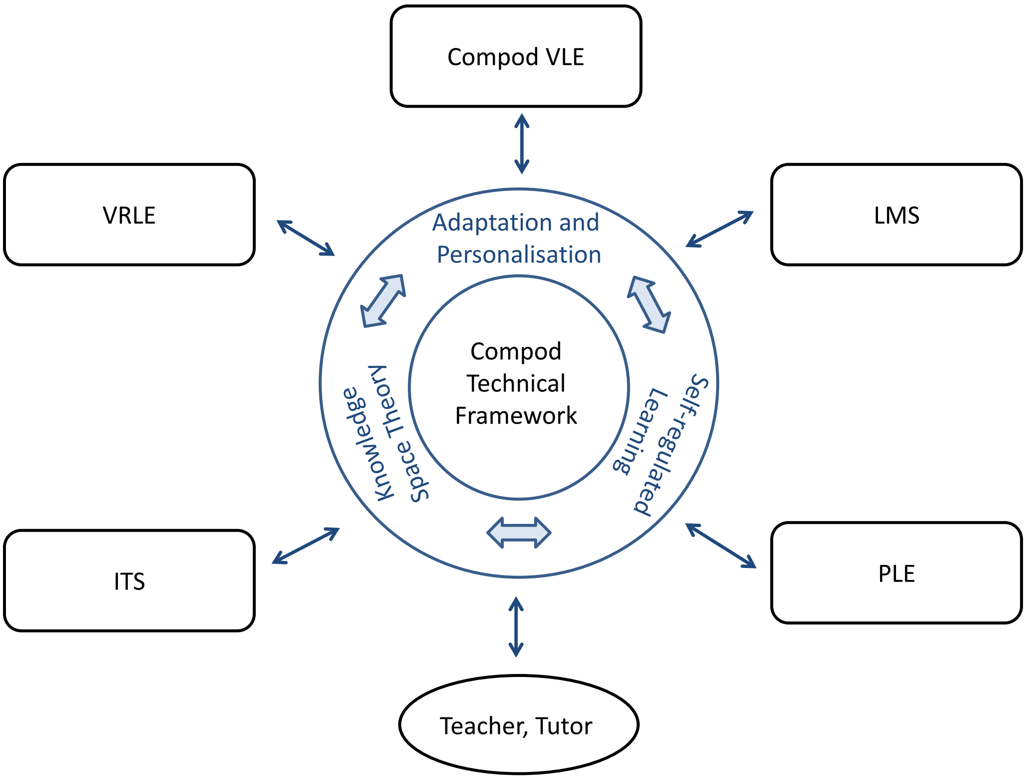


Figure 1.1: This diagram shows the overall approach of this thesis. A technical framework in the centre is surrounded by a conceptual framework featuring different learning concepts. Both technical and conceptual framework are used by external Virtual Learning Environments.

The **conceptual framework** is based on AEH, SRL, and CbKST. Referring to to the first objective (objective a) AEH addressed personalised learning, SRL addresses self-regulated learning, and CbKST addresses competence-based learning. AEH provides means of adapting structured educational content to the goals, interests, knowledge, and other personal characteristics of the learner. Based on the tradition of ITS, well elaborated technical models have been elaborated that determine the personalisation and adaptation. SRL has its roots in pedagogy and psychology and provides a theory how learners meta-cognitively control their learning process. CbKST is a mathematical-psychological theory for representing domain and learner knowledge and for adapting the learning paths and assessment of the knowledge and competences of the learner. These three learning concepts address different aspects of the leaner and the learning process. The conceptual framework integrates them to a holistic approach, in order to benefit from the advantages of each of them.

The **technical framework** translates the conceptual framework into a technical framework that includes a model how the conceptual framework with all its features can be implemented. Furthermore, it includes a software implementation that realises the conceptual framework. The software is called *Compod*, which is an acronym of *Competence Pod* meaning that it is a software component dealing with competences. Compod is designed as a system that includes several components. The Compod service deals with the core features implementing the conceptual framework. The Compod authoring and teacher tool is Web-based tool for creating and managing courses. The Compod VLE is a reference application of a VLE that demonstrates how to use the Compod services. As a core feature the Compod service serves as a component that exposes the learning approach of the conceptual framework to external VLEs. In this way, the different types of VLEs can access the technical framework as a service, in order to incorporate its learning approach. Four different types of VLEs are selected as testbeds for this approach. These are ITSs, LMSs, PLEs, and Virtual Reality Learning Environments (VRLEs).

From a **learner perspective**, these VLEs serve as interface for the learning approach defined in the conceptual framework. The learners can use these environments in the usual manner with all their characteristics and advantages. Additionally, they get learning support in terms of content structuring, personalised support for knowledge acquisition, competence development, and self-regulated learning. From the perspective of teachers, tutors, and educational institutions, they can also stick to their deployed VLE and can enrich them with these features. Existing content, user accounts, and other settings in their VLE can be further used, but in an enriched way. Furthermore, they can monitor the learning behaviour and outcomes of indiviudal learners and groups.

The research to elaborate this approach is guided by four research questions. These research questions cover the individual aspects of the overall approach. A final discussion how they are addressed is presented in the conclusion (Chapter 10). This also includes the scientific publications that are related to them. The research questions are as follows:

RQ 1: How can the three learning concepts Adaptive Educational Hypermedia (AEH), Self-regulated Learning (SRL), and Competence-based Knowledge Space Theory (CbKST) be integrated on a conceptual level in a common framework?

RQ 2: How can the conceptual framework be translated into a technical framework and system, so that it provides personalised learning support for knowledge acquisition, competence development, and self-regulated learning?

RQ 3: How can the technical framework be used by existing Virtual Learning Environments (VLEs) in a way that they benefit from the supported learning approach.

RQ 4: What is the effect, advantage, and acceptance of the overall approach for learners, teachers, and tutors?

1.3 Scope and Structure of Work

The **scope** of this thesis encompasses the research, elaboration, and development of the overall approach and its aspects. This includes the analysis of three learning concepts AEH, SRL, and CbKST regarding their individual aspects, the elaboration of the the conceptual framework, the design of the technical framework, the development of an according software component, and the evaluation of the approach and software. Considering these phases, the work done this thesis includes the analysis of psychological and pedagogical theories, the design of a conceptual and technical framework, software development, and evaluation.

There are also a lot of topics and aspects that are not part of this work. The research and application field of TEL has developed to a very broad area with numerous learning approaches, technical solutions, and application areas. This work focuses only on three learning concepts and does not take into account many other approaches, such as game-based learning, gamification, project-based learning, or collaborative learning.

The **structure** of this thesis follows the overall approach and scope described above. It consists of three main parts, which are (a) related work and theoretical foundation, (b) concept and implementation, and (c) evaluation and proof of concept. An overview of the structure is outlined in Figure 1.2.

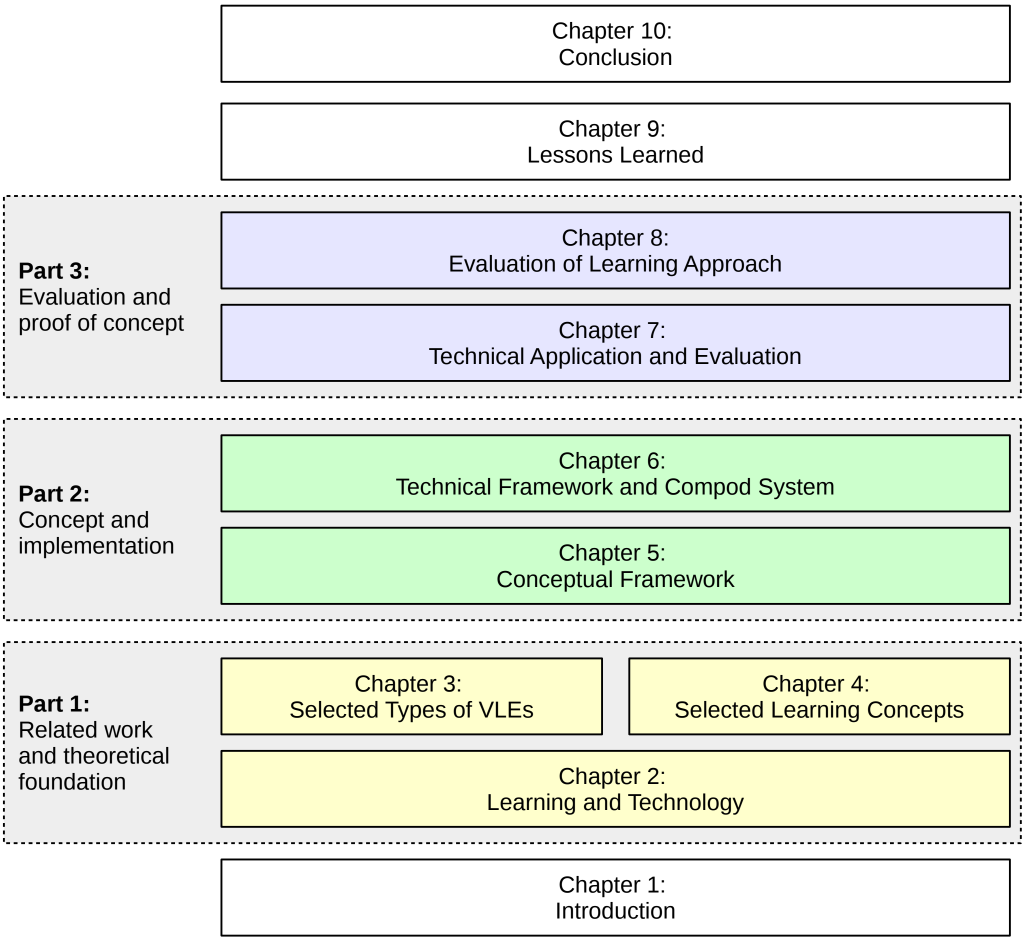


Figure 1.2: This diagram outlines the structure of this thesis.

The first part is the **related work and theoretical foundation**, which is elaborated in Chapters 2-4. A general overview of the field of TEL including a historical background is elaborated in Chapter 2. Chapter 3 presents the four types of VLEs that are addressed as testbeds for the developed approach. Chapter 4 discusses the three learning concepts that are basis for the conceptual framework. While Chapter 2 gives a general overview of research and application in TEL (that are out of scope of this thesis), the other two chapters build the theoretical and practical basis for it.

The second part consists of **concept and implementation**, which is presented in Chapters 5-6. The conceptual framework that integrates the three learning concepts into a new learning approach is described in Chapter 5. Details of the technical concept and related implementation is described in Chapter 6. The core component of the implementation is the Compod service where the conceptual framework is realised. In addition to that, Compod VLE constitutes a reference implementation of VLE, which demonstrates a possibility how the Compod service can be used. Together with an authoring and teacher tool, Compod service and Compod VLE build the Compod system.

The third part is dedicated to the **evaluation and proof of concept**, which is described in Chapters 7-8. First, it is shown how the Compod system has been used by for different VLEs. This application of the Compod service in different contexts serves as a proof of concept that the software with its learning approach can be used by different types of VLEs. Second, the learning approach itself is evaluated with Compod VLE in a user study. This demonstrates the usefulness of the learning approach and the technical implementation.

Finally, there is a chapter on lessons learned, which discusses the barriers and insights gained during the work on this thesis (Chapter 9). A conclusion with an overview and research results is presented in Chapter 10. The research results are discussed in the light of the research questions listed above.

1.4 Contribution

This section gives an overview of the scientific publications in journal and conference proceedings that were made during the work on this thesis. They contain intermediate steps and versions of the framework and application. In the first part, publications are listed and commented that contain essential aspects of this thesis. In the second part, publications are listed that contain work in the research area of this thesis, which, however, are not in the centre of this thesis.

Relevant publications used for this work

1. **Nussbaumer, A.**, Hillemann, E.-C., Gütl, C., & Albert, D. (2015). A competence-based service for supporting self-regulated learning in virtual environments. Journal of Learning Analytics, 2(1), 102–133. doi: 10.18608/jla.2015.21.6

This is an essential publication that describes the conceptual framework, the Compod VLE, and the evaluation of the learning approach. For this special issue the Journal of Learning Analytics requested contributions that integrate Learning Analytics (LA) and SRL. As a core part of the overall concept, SRL is empowered through the personalised support combines monitoring, analysis, recommendation, and feedback. This combination is also regarded as LA. The evaluation plan was elaborated together with Eva Hillemann and all co-authors provided useful ideas and feedback to the content of this publication. More information is provided in Chapters 5–6 and 8.

2. **Nussbaumer, A.**, Gütl, C., & Hockemeyer, C. (2007). A generic solution approach for integrating adaptivity into web-based e-learning platforms. In M. E. Auer & A. Al-Zoubi (Eds.), Proceedings of the International Conference on Interactive Mobile and Computer Aided Learning (IMCL 2007) (p. 1-9). Kassel, Germany: Kassel University Press. Retrieved from http://www.upress .uni-kassel.de/katalog/abstract en.php?978-3-89958-276-5

3. **Nussbaumer, A.**, Gütl, C., & Albert, D. (2007). Towards a web service for competence-based learning and testing. In C. Montgomerie & J. Seale (Eds.), Proceedings of the

World Conference on Educational Multimedia, Hypermedia and Telecommunications (ED-MEDIA 2007) (pp. 1380–1385). Chesapeake, VA, USA: Association for the Advancement of Computing in Education (AACE). Retrieved from https://www.learntechlib.org/p/25556

These two publications contain the initial ideas of integrating CbKST into LMSs. They state that research on TEL in terms of CbKST did not find their way into the educational sector. Thus LMSs should be opened up and integrate CbKST learning concepts. The co-authors supported the approach though discussions. More information is provided in Chapters 4 and 6.

4. **Nussbaumer, A.**, Steiner, C. M., & Albert, D. (2008). Visualisation tools for supporting self-regulated learning through exploiting competence structures. In K. Tochtermann & H. Maurer (Eds.), Proceedings of the International Conference on Knowledge Management (IKNOW 2008) (pp. 288–295).

5. **Nussbaumer, A.** (2008). Supporting self-reflection through presenting visual feedback of adaptive assessment and self-evaluation tools. In M. E. Auer (Ed.), Proceedings of the 11th International Conference on Interactive Computer-aided Learning (ICL 2008) (pp. 1–8). Kassel, Germany: Kassel University Press. Retrieved from http://www.icl-conference.org/archive.htm

6. Albert, D., **Nussbaumer, A.**, & Steiner, C. M. (2008). Using visual guidance and feedback based on competence structures for personalising e-learning experience. In Proceedings of the 16th International Conference on Computers in Education (ICCE 2008) (p. 3-10). Jhongli City, Taiwan: Asia-Pacific Society for Computers in Education (APSCE). Retrieved from http://www.apsce.net/icces_previous.php?id=1017

7. Steiner, C. M., **Nussbaumer, A.**, & Albert, D. (2009). Supporting self-regulated personalised learning through competence-based knowledge space theory. Policy Futures in Education, 7(6). doi: 10.2304/pfie.2009.7.6.645

These publications contain the initial work on integrating CbKST with SRL and how this combined approach can be supported with visualisation tools. For this reason the Open Learner Model (OLM) approach is employed that visualises domain and user model structured according to CbKST principles. Furthermore, an assessment procedure and learning path creation based on CbKST has been implemented in these tools. This work was performed in the context of the iClass[2] research project. The co-authors significantly contributed to the conceptual idea of combining CbKST and SRL. More information is provided in Section 7.1.

8. Hockemeyer, C., **Nussbaumer, A.**, Lövquist, E., Aboulafia, A., Breen, D., Shorten, G., & Albert, D. (2009). Applying a web and simulation-based system for adaptive competence assessment of spinal anaesthesia. In M. Spaniol, Q. Li, R. Klamma, & R. W. Lau (Eds.), Advances in Web Based Learning – ICWL 2009. Lecture Notes in Computer Science (Vol. 5686, pp. 182–191). Berlin Heidelberg: Springer. doi: 10.1007/978-3-642-03426-8 23

This publication describes the work on competence assessment in the context of a simulator for spinal anaesthesia. The assessment items were performed on the simulator and the assessment algorithm was conducted on Compod system. This work was performed in the context of the MedCAP[3] research project. While the co-authors were responsible for the simulator, the assess-

[2] iClass is a FP6 research project funded by the European Commission
[3] MedCAP is a research project funded under the Life-Long-Learning programme of the European Commission

ment items, and the competence structure, the contribution related to this thesis concerned the assessment algorithm and service. More information is provided in Section 7.4.

11. **Nussbaumer, A.**, Gütl, C., Albert, D., & Helic, D. (2009). Competence-based adaptation of learning environments in 3d space. In M. E. Auer & A. Al-Zoubi (Eds.), Proceedings of the International Conference on Interactive Mobile and Computer Aided Learning (IMCL 2009) (pp. 103– 108). Kassel, Germany: Kassel University Press. Retrieved from http://www.upress.uni-kassel.de/katalog/abstract_en.php?978-3-89958-479-0

This publication presents an approach how Compod is used in the VRLE SecondLife. A learning landscape has been created in SecondLife, which makes use of adaptive learning path recommendations of Compod. The co-authors provided useful ideas and feedback for the work of this publication. More information is provided in Section 7.2.

9. Dimache, A., Roche, T., Kopeinik, S., Winter, L. C., **Nussbaumer, A.**, & Albert, D. (2015). Suitability of adaptive self-regulated e-learning to vocational training: A pilot study in heat pump system installation. International Journal of Online Pedagogy and Course Design (IJOPCD), 5(3), 31– 46. doi: 10.4018/ijopcd.2015070103

10. Kopeinik, S., **Nussbaumer, A.**, Winter, L.-C., Albert, D., Dimache, A., & Roche, T. (2014). Combining self-regulation and competence-based guidance to personalise the learning experience in Moodle. In D. G. Sampson, J. M. Spector, N.-S. Chen, R. Huang, & Kinshuk (Eds.), Proceedings of 14th IEEE International Conference on Advanced Learning Technologies (ICALT 2014) (pp. 62–64). New York, USA: IEEE. doi: 10.1109/ICALT.2014.28

These publications describes the work on supporting SRL based on CbKST in Moodle. A plugin was developed for Moodle that provide SRL features to the learners. This plugin is connected with the Compod service that facilitates SRL features. This work was performed in the context of the Innovret[4] research project. While the co-authors (especially Simone Kopeinik) were responsible for the Moodle plugin, the contribution related to this thesis encompasses the learning approach facilitated by the Compod service. More information is provided in Section 7.5.

12. **Nussbaumer, A.**, Gütl, C., & Neuper, W. (2010). A methodology for adaptive competence assessment and learning path creation ISAC. In J. Schreurs (Ed.), Proceedings of the International Conference on Interactive Computer-aided Learning (ICL 2010) (p. 1136-1139). Kassel, Germany: Kassel University Press. Retrieved from http://www.icl-conference.org/archive.htm

This publication presents an approach how Compod is used in the tutoring system ISAC[5]. Compod has been used for adapting the learning path of the mathematical tasks provided by ISAC. The co-authors provided useful ideas and feedback for the work of this publication. More information is provided in Section 7.3.

13. **Nussbaumer, A.**, Steiner, C. M., McCarthy, N., Dwane, S., Neville, K., O'Riordan, S., & Albert, D. (2015). An approach for training decision making competences in a multi-modal online environment. In Proceedings of the 23rd International Conference on Computers in Education (ICCE 2015) (pp. 97–99). Jhongli City, Taiwan: Asia-Pacific Society for Com-

[4] Innovret is a research projected funded under the Life-Long-Learning programme of the European Commission
[5] http://www.ist.tugraz.at/isac/

puters in Education (APSCE). Retrieved from http://icce2015.csp.escience.cn/dct/page/70022

This publication presents an approach how to use Compod for teaching decision making competences. While the original idea presented an approach for connecting a virtual environment with Compod, in fact Compod VLE has been used afterwards to provide a course on decision making competence training. This work was performed in the context of the S-HELP[6] research project. The co-authors were responsible for the elaboration of the competence model. The training and assessment was conducted with the Compod system. More information is provided in Chapter 8.

Further relevant publications

14. **Nussbaumer, A.**, Dahrendorf, D., Schmitz, H.-C., Kravcik, M., Berthold, M., & Albert, D. (2014). Recommender and guidance strategies for creating personal mashup learning environments. Computer Science and Information Systems (ComSIS), 11(1), 321–342. doi: 10.2298/CSIS121210011N

15. **Nussbaumer, A.**, Dahn, I., Kroop, S., Mikroyannidis, A., & Albert, D. (2015). Supporting self-regulated learning. In S. Kroop, A. Mikroyannidis, & M. Wolpers (Eds.), Responsive Open Learning Environments (pp. 17–48). Cham, Heidelberg, New York, Dordrecht, London: Springer International Publishing. doi: 10.1007/978-3-319-02399-1_2

16. Renzel, D., Klamma, R., Kravcik, M., & **Nussbaumer, A.** (2015). Tracing self-regulated learning in Responsive Open Learning Environments. In F. W. Li, R. Klamma, M. Laanpere, J. Zhang, B. F. Manjon, & R. W. Lau (Eds.), Advances in Web-Based Learning – ICWL 2015. Lecture Notes in Computer Science (Vol. 9412, pp. 155–164). Cham, Heidelberg, New York, Dordrecht, London: 7Springer International Publishing. doi: 10.1007/978-3-319-25515-6_14

These publications present work on the use of learning tools form the perspective of SRL and PLEs. The key topics include the creation of a Mash-up recommender tool that provides support in the creation of a learning environment that enables and facilitates SRL. Additionally, other techniques for supporting SRL in PLEs have been elaborated, including instructional videos, predefined PLEs, and activity recommenders. This work was performed in the context of the ROLE[7] research project. Most of the work was performed in collaboration with the co-authors under the guidance of my work package lead.

[6] S-HELP is a FP7 research project funded by the European Commission

[7] ROLE is a FP7 research project funded by the European Commission

Chapter 2

Learning and Technology

The relationship and mutual influences between learning and technology have led to intense and versatile research activities and have become important in educational institutions and beyond. On the one hand learning practices have been changed and advanced by the use of technologies, and on the other hand the development of technologies for learning has been influenced by this application field. Though technology in the context of learning is mostly associated with computers and information technology, also other technologies, devices, and equipment played an important role in the past.

Many different terms have been coined that describe the liaison between learning and technology. The most popular terms, Technology-enhanced Learning (TEL) and Educational Technologies (EduTech), are often synonymously and rarely clearly defined. A definition of EduTech is given by the Association for Educational Communications and Technology (AECT): *"Educational Technology is the study and ethical practice of facilitating learning and improving performance by creating, using and managing appropriate technological processes and resources"* (Richey, 2008). This definition refers to technology as resources and processes that enables learning and improves the performance in organisations. Kirkwood and Price (2014) understand TEL as *"the application of information and communication technologies to teaching and learning"* and elaborate what "enhancement" actually means. While the first definition refers to technology that facilitates learning, the second definition focuses on the enhancement of learning.

This chapter gives and overview on the broad field technological developments in the context of learning and teaching. Section 2.1 outlines the historical development of technologies in the context of learning and teaching. Section 2.2 gives an overview of learning theories from a psychological point of view. Then, in Section 2.3 approaches and concepts are presented and discussed that are relevant in research and practice. The goal of this chapter is to demonstrate the diversity and complexity of technologies for learning in the context of research and practice. This allows to position the scope of this thesis in the broad field of TEL, which is presented in Section 2.4.

2.1 Historical Background

This section gives a short overview of the historical evolution of technologies, devices and equipment that were used for learning and teaching support. This overview follows the elaborations available in literature (Kidd, 2010; Kroell & Ebner, 2010; Reiser, 2001; Saettler, 2004; Westera, 2010).

Technology-enhanced Learning (TEL) did not start with the invention of computers, but dates back in history much further. Saettler (2004) sees the origin of educational technologies in the time of ancient cultures that invented pictographs that were pained in cave, in order to explain animal hunting. He regards educational technology as a process where a kind of knowledge was systematically applied to instruction using the available technology. The first known inherently systematic procedure of mass instruction took place in ancient Greece in the 5th century BC. The Elder Sophists, a small group of peripatetic teachers in Athens, gave lessons to groups of people. They followed one of three methods, (a) giving a well-prepared lecture on a topic, (b) an extemporised lecture on a topic chosen by the audience, or (c) offering a free debate with another Sophist on a topic chosen by the audience.

Over the centuries the knowledge to be conveyed increased and the technological developments and inventions evolved, which also lead to a more complex technology of instruction. For example, the invention of the printing press and the blackboard led to new possibilities of teaching classes. In the 19th century, James Sully presented the first complete discussion of the function of science in the teaching process. Sully believed that the teacher must be aware of the psychological laws and has to apply them in systematic and practical instructions, in order to perform successful teaching Saettler (2004).

In the beginning of 20th century, the invention of the cinematograph led to the development of **educational films**. In 1889 the first model of a film projector (Edison kinetoscope) was demonstrated at the Edison labs. This was a simple device where a film can continuously between a magnifying lens and a light source. Inspired from this invention, many other film projectors with significant improvements were developed. Using this technology, films of different topics were developed, such as advertising films, health films, war propaganda films, and films for schools that were called educational films. In 1909 Charles Urban published a catalogue of educational films that contained more than thousand titles categorised into 30 main topics. Thomas A. Edison was so excited about the educational possibilities of the motion picture, that came to the conclusion that books in schools will soon be obsolete and educational films will teach any kind of human knowledge (Saettler, 2004) .

Almost at the same time when the first film projector was invented, Heinrich Rudolf Hertz proved the transmission of electromagnetic waves in an experiment in 1888 Saettler (2004). This led to the development of devices that were able to transmit wirelessly the human voice, which was called radio technology. Based on this technology, radio broadcasting was used as mass communication in the early 1920s. As soon as the technology was ready to use, the idea of applying it for teaching purposes came up and led to the **instructional radio**. The delivery of content via the radio was employed in different ways with different teaching strategies, such as direct classroom teaching, supplementary teaching, adult teaching, and distance learning. Especially, in rural areas so-called *Schools of the Air* can teach pupils at home using radio broadcasting. This type of schools is still available in Australia.

Similar to the development and deployment of the instructional radio, the **instructional television** emerged from the invention of the television in the 1920s. The combination of visual and audio in educational content was appealing for the educational sector. After first experiences in the 1950s, television courses were established at all levels of education in the 1960s. Television was used for illustration and enrichment of traditional classes, but also distant university courses were established. There was a need for open access and distance learning that could be addressed by instructional television. However, there were also doubts if television could sufficiently serve as the core teaching medium, as it is a one-size-fits-all medium and does not allow interaction with teachers (Westera, 2010).

A very successful supplementary method of courses was the use of **audio and video cassettes**. Their development started in the 1950s and they constituted a cheap and easy to use possibility for learning and teaching instrument. They provided a flexible way of give guidance for written material, that students could use at home. Hence, they also could be used for distance learning. Though these media are now outdated, the underpinning concepts are still in use. While CD-ROMs and DVDs are intermediate technologies, the basic concepts presently appear in portable audio and video players, as well as in audio and video streaming services (Westera, 2010).

A different type of a technology for learning was invented by George Pressey in the 1920s. Pressey, a cognitive psychologist, created **teaching machine** that could conduct multiple choice tests. The machine had a window where the question was presented and four keys to input the answer. The machine did not continue to the next question until the student entered the correct answer. This was the first demonstration that a machine was able to teach, as the student learned from the machine's feedback if the answer was correct or not. Pressey believed that this machine would relief teachers from time consuming routine tasks, but also would increase the learning effectiveness and learning outcomes of the students, and thus would radically change the educational system (Westera, 2010).

A few decades later, in the 1950s a new series of machines were created that provided other and types of tasks to the students. Instead of answering with multiple-choice alternatives, students could enter their own answers that were compared with pre-composed answers. The idea of these machines followed the **programmed learning** (or programmed instruction) theory of B. F. Skinner, which aimed at dividing the learning content into many small pieces (frames) that should be learned and tested individually and step-by-step. Skinner saw an advantage in this approach, as it was based on recall and not on recognition as the teaching machines using multiple choice questions (Reiser, 2001).

A significant change of educational practices came in with the development of **microcomputers**. Starting in the 1960s, pioneers at IBM developed the trial version of a computer-based instructional program for schools. This new branch of research and development was called Computer-assisted Instruction (CAI). Following the idea of the teaching machines, more complex and versatile instruction programs could be created with microcomputers. For example, a group directed by Patrick Suppes developed an instructional programs for elementary schools. Another influential work resulted in the educational system PLATO by Don Bitzer in the 1970s, which was the first online educational system featuring community tools, such as forums, chat. The system was realised through a timesharing system operated by a mainframe computer with several terminals where students could work in parallel and communicate with each other. Addressing individual students who were enabled to perform tasks and learning process on a microcomputer, a big step forwards was made towards individualised instruction (Reiser, 2001). The further research and development on CAI led to Intelligent Tutoring Systems (ITSs) and AEH systems, which is described in detail in Section 3.1.

Along with the advancement microcomputers that evolved to affordable personal computers in the 1980s, the audio-visual instruction stream was taken over by computers. The main focus of audio-visual instruction was the delivery of learning content, as it was already done by film and audio lectures. The content was delivered on CD-ROMs, DVDs, and later downloaded from the Internet and presented in an interactive way by personal computers.. This type of instruction was named Computer-based Training (CBT). Using **multimedia** content was a key feature of this training material, which consisted of different types of media (text, image, audio, video, etc.) (Kidd, 2010).

With the availability of the Internet and **World Wide Web** (WWW) for a broader public in the 1990s, a new form of computer-based learning appeared, which was called Web-based Training (WBT). WBT used continuously evolving Web technologies to facilitate computer-based training, such as online communication, Web 2.0 approaches, and back-end services. This development led to virtual environment as described in the next chapter. WBT provides a strong foundation for distance education, which has been adopted by large educational institutions (Kidd, 2010).

2.2 Learning Theories

Learning is a complex process that deals with the acquisition of new behaviour, knowledge, skills, and attitudes. It is influenced by environmental events and factors, as well as personal experiences, states, and traits. A rather general definition is given by Gerrig and Zimbardo (2002): *"Learning A process based on experience that results in a relatively permanent change in behaviour or behavioural potential"*. Learning theories describe the learning process by defining the elementary components, including the triggers and information that stimulate learning, the means how learning takes place, and the results addressing the changes in behaviour (Driscoll, 2005). This section presents the most important learning theories including information how they can be taken up the TEL systems.

Behaviourism

Behaviourism is a psychological theory that only takes into account the observable behaviour. From the perspectives of behaviourism, learning is the acquisition of new behaviour based on environmental conditions. Mental activities and processes, such as emotions, understanding, or interests, are not neglected, but regarded as not relevant. Instead, the behaviourist theory investigates human behaviour by analysing the relations between stimuli and reactions. Two major variants have been developed, classical conditioning and operant conditioning. Originally developed by Watson, Thorndike, and Pavlov, classical conditioning refers to a situation when a neutral stimulus paired with an unconditional stimulus can evoke a response. Operant conditioning, mainly developed by B. F. Skinner, occurs when a wanted response to a stimulus is awarded or a unwanted response is punished. Hence, learning is understood as the step-by-step adoption of single pieces of behaviours by applying reward and punishment (Skinner, 1974).

The behaviourist theory provoked numerous educational developments from programmed instruction to computer-aided instruction (see Section 2.1). Following this research stream, Atkins (1993) and Robinson, Molenda, and Rezabek (2008) proposed several instructional design guidelines and characteristics for an educational system that lead to improved learning outcomes. According to them, programmed instruction already demonstrated that learners can learn effectively without instructions from the teacher. In doing so, the learners became active participants in their learning process. Though they did not have control the learning process, they had to actively response to the individual instructional steps. Some of the most important characteristics of an behaviourist-oriented learning system are:

- Learning material should be broken down into small instructional steps.
- Learning activities should be sequenced for increasing difficulty.
- Tasks should be adapted to the learner's knowledge state, in order to ensure low error rates.
- Activities should be responded with carefully designed responses and feedback.
- At certain points tests or assessments with results presented to the learner should be included in the learning activities

Cognitivism

Cognitive psychology is the study of higher mental processes such as attention, language use, memory, perception, problem solving, and thinking (Gerrig & Zimbardo, 2002). Instead of focusing on observable behaviour, cognitive psychology focuses on internal cognitive activities, in order to explain human behaviour and performance. Internal cognitive activities include thinking and reasoning, perception, problem solving, and memory functions. Learning as major field of of cognitive psychology is explained with the change of knowledge states, the processes how information is perceived, stored, and organised by the mind, as well as how humans control their memory, thinking, and mental representations (Ertmer & Newby, 2013). Learning is not so much concerned with what the learners do, but rather what they know and how they acquire knowledge.

Learning in cognitive psychology is not expressed by a single theory, but a several theories have been developed that explain learning and provide information how to improve it. The following list given an overview of the most important ones (Robinson et al., 2008):

- *Piaget's theory*. Piaget's theory of cognitive development explains how humans acquire and use knowledge. The theory distinguishes between two main processes: *assimilation* and *accommodation*. Assimilation is the process how humans integrate new knowledge into existing framework of own mental structures. It occurs when new information is received that can be related to existing knowledge. Accommodation occurs, when new information does not fit to existing knowledge and the existing mental structures have to be changed, in order to integrate the new knowledge.
- *Information processing theory*. This theory uses the computer as a metaphor, in order to explain learning. Learning is a process in which information is transformed ans stored by a

series of mental processes, such as attention, perception, short term memory, and long term memory.

- *Schema theory*. This theory suggests that knowledge stored in long-term memory is more abstract originally received from concrete experiences. In order to transform concrete information into an abstract form, superordinate, representational, and combinatorial processes are involved.
- *Cognitive load theory*. The cognitive load theory refers to information processing and schema theory. It suggests that the mental effort of the working memory has to be balanced while processing and integrating new knowledge into long-term memory because of its finite capacity (Sweller, Van Merriënboer, & Paas, 1998).
- *Gestalt theory*. Gestalt psychology helps to understand the way visual information and patterns are perceived and recognised by humans. A set of principles explain several effects of visual perception. For example, the proximity principle states that visual elements are perceived as a group, if they are visually close to each other. The Gestalt principles of perceptual organisation provide a useful theoretical basis for deriving basic principles in designing user interfaces (J. Johnson, 2010).

Several conclusions and consequences of the cognitive learning theories for the design of learning content and systems can be drawn including the structure and presentation of the content, as well as the tasks to be performed with a learning system (Robinson et al., 2008). Several frameworks have been created that give guidelines how to design learning content and system based on cognitive learning theories, for example the Events of Instruction by Gagne and Medsker (1996) and the Cognitive Training Model by Foshay, Silber, and Stelnicki (2003). Some of the guidelines recommended by these frameworks are described in the following list:

- The reasons for learning the lesson content should be explained, in order to gain the learner's attention.
- Links to prior or prerequisite knowledge and skills, as well as contextual information of the content should be provided
- It should be explained what is learned during the learning session, which knowledge and skills are expected to acquire.
- The content should be carefully structured, in order to make it meaningful, comprehensible, memorable, and appealing for the learner. This includes the organisation of the content into appropriate units.
- An appropriate layout of images and text helps learners to focus on important information and to better understand and remember key concepts. Visual designs also makes it easier and faster to perceive information.
- Different sensory modalities (e.g. verbal, visual, auditory) are processed differently by the brain. The design of learning material should take into consideration different presentation forms where appropriate.
- Opportunities should be provided to practice the new knowledge and skills. During the practice, feedback on answers and general hints should be provided.
- Learners should be helped to transfer the new knowledge and skills to other situations, for example simulation of job situations.

Constructivism

The basic assumption of constructivism is that the reality cannot be perceived as it really is. Instead, humans construct their own view and knowledge of the world and reality using current knowledge and perceived information (Ertmer & Newby, 2013). Constructivism has its root in cognitivism, as both focus on mental activities. However, unlike cognitivism that considers the mind as a reference tool to the real world, in constructivism the mind creates its own reality by processing input from the world. Hence the constructivist learning theory assumes that learners create knowledge and meaning, instead of acquiring it. They build personal interpretations based on individual experiences and interactions in relation to the environmental context where they were made.

This assumption leads to several concepts and approaches for TEL solutions and provoked recommendations for for the design of learning environments (Driscoll, 2005; Ertmer & Newby, 2013; Robinson et al., 2008). A number of these concepts originate from cognitivism. Some examples are listed here:

- *Information sources*. Learning content should not be pre-specified, but the learner should have access to information from many sources. Different information sources stimulate multiple perspectives on ideas and concepts. This way the learner have to search and evaluated content and information, and thus construct own knowledge.
- *Realistic environments*. Instead of acquiring abstract knowledge in artificial environments, constructivist approach suggest to situate the learning into a realistic context.
- *Problem-based learning*. Instead of passively consumed information, problems should be posed to the learner, which will stimulate the thinking and knowledge construction. Problems should be authentic and drive the knowledge construction (instead of creating problems out of isolated pieces of knowledge).
- *Collaborative learning*. Learning should take place in groups (mediated though technology, but also in the physical space). Collaboration, discussions, and social negotiations support knowledge construction.
- *Ownership of learning*. The learners are not passive consumers, but should take over control and responsibility of their learning processes and needs. They be able to manipulate information and to control the own learning process.
- *Cognitive apprenticeship*. Realistic problems in combination with multiple information sources can be very demanding for novice learners. Therefore, the difficulty level of tasks and information should be adapted to the expert level of the learners. Additionally, especially novice learners need support, such as coaching and scaffolding that guide them through the tasks.

A learning environment that supports the constructivist learning theory is described by Jonassen (1999). The underpinning concept of this learning environment is a model that supports the aforementioned approaches and provides different types of help. In this model, (a) the problem is put into the centre and encompassed by (c) information tools, (d) cognitive tools, (e) collaboration tools, and (f) social (realistic) contexts. In addition to this structure, support mechanisms are proposed: (1) Help functions that provide immediate requested information, (2) couching that provides motivational, regulative, and reflective support, and (3) scaffolding that provides support for doing a specific task.

2.3 Educational Context and Research Areas

This section gives an overview of the major practices, approaches, and research areas of Technology-enhanced Learning (TEL). Since TEL has become a huge field with all their theories, technologies, and applications, this overview will rather be on a general level than complete. It emphasises the interplay between technology and educational contexts in the light of practice and research.

Learning Topic and Educational Context

Learning topics and objectives are key drivers for TEL approaches. Besides many knowledge fields, two learning areas are in the centre of recent TEL activities. First, competence in Science, Technology, Engineering, and Maths (STEM) is recognised as an important educational goal in today's society. Since STEM disciplines are sometimes not attractive or too difficult for young people, TEL approaches often tried to address these issues (Kudenko & Gras-Velázquez, 2014). Another major learning topic is on a meta-level targets so-called 21st century skills. New demands in modern society need more than profound domain knowledge, but also require abilities on a meta-level, such as successful communication and negotiation, collaboration on learning tasks, critical thinking in terms of evaluating knowledge and information, and creativity in knowledge generation (R. E. Anderson, 2008). Furthermore, self-regulation of the own learning process (see Section 4.2 is a key competence, because it deepens the understanding, allows school pupils to learn outside the classroom, and provides a basis for life-long learning. Both STEM and 21st century skills are major targets of TEL research.

TEL solutions are applied in different contexts, where each context has its specific requirements and opportunities. The learning contexts can be divided into four main categories. The first context consists of formal educational organisations including schools and higher educational institutions (e.g. universities). These organisations have rather strict curricula and defined learning outcomes. Second, independent training and learning institutions are another category of learning contexts. For example, vocational training is an important sector to educate workers and employees. Third, the workplace constitutes a special learning context, because workers and employees often have to improve their knowledge and skills during or in between their work, in order to master their everyday's tasks. Finally, people also learn individually without external goals, in order to advance themselves or to increase their employability factors.

Along with the aforementioned educational contexts, there are several aspects that influence and determine how learning takes place. Formal, non-formal, and informal learning distinguishes learning according their curricula, defined learning goals, role of teachers, location, and schedule. Formal learning targets formal educational organisations with defined structures, such as location, time, objectives, and teachers. Non-formal learning takes place in institutions outside the formal organisations, but on a regular basis in defined settings. Informal learning happens when learners learn on their own pace, from experiences and daily life activities, and often without a defined goal. Another important aspect is collaborative learning, which includes learning in groups, discussion and debates on learning topics, joint elaboration of tasks, and peer assessment.

Many sorts of learning have been developed that make learning more attractive and effective. Experiential learning focuses on learning through experience and reflection of own actions. Activity-based learning suggests concrete activities of the learners, such as demonstrations, quizzes, small projects, and brainstorming. Blended learning describes several models how both classroom and online learning can be combined, in order to benefit from the advantages of each type.

Integration of Technology and Education

Numerous TEL approaches have been developed that integrate learning contexts, aspects, and theories with technology in many different ways. They are on different levels in terms of the technological, pedagogical, and psychological completeness. While some of them comprise and integrate many technical and educational aspects, there are others that are rather isolated approaches or are part of other approaches. In the following list, a selection of well-known approaches are shortly described (Duval, Sharples, & Sutherland, 2017).

- *Game-based learning*. Games are a method to increase motivation, enjoyment, and flow experience during learning. Combining digital games with a learning agenda transfers the advantages to games to the educational area. However, this requires a careful design of the pedagogical approach and the game design in the light of the learning objective, which is often expensive time consuming.
- *Gamification*. Gamification refers to the integration of game elements (e.g. scores or rewards) in non-game environments. The rationale of this approach is to achieve the benefits of games in other applications.
- *Mobile learning*. The emergence of mobile devices (laptops, tablets, smart phones) provides new possibility for learning with technology. They can be used at any time and on any place, which makes learning more flexible. Personalisation and adaptation methods can take into account characteristics not available on stationary computers, such as current time, location, and context.
- *Collaborative and Social Learning*. Computer-supported Collaborative Learning (CSCL) targets a learning situation where people learn together with the use of computer systems. As indicated above, learning together includes joint activities, such as discussions, shared activities, and group works. Computers can support these activities in many ways, for example by providing a virtual environment, communication tools, collaboration tools, or scaffolding and assistance.
- *Massive open online courses (MOOCs)*. MOOCs aim at opening up regular courses to a very broad audience and making them available online. Typically, MOOCs provide courses of higher educational institutions for distance learning in formal and informal manor. In many cases MOOCs are collections of recorded lecture videos integrated with additional learning material and tasks.
- *Virtual and Remote Laboratories*. Especially for physics and engineering learning, virtual and remote laboratories provide the possibility to conduct virtual experiments. Such experiments have many advantages, for example information can be shown that is not visible in real space, features of the real space can be altered, and creation of experiment is less expensive.

Assessment, Monitoring, and Feedback

A central point of learning and teaching is the assessment of knowledge and skills, often called Computer-based Assessment (CBA) in the context of TEL. In a review at the higher education sector (JISC, 2007), main aspects of CBA are emphasised. In general, well-designed and well-deployed assessment procedures can foster more effective learning for a wider diversity of learners. It is a very useful way of identifying support needs of learners and can provide an essential basis for any kind of personalisation. Furthermore, it is a tool for ensuring and enhancing the quality of an educational system, as it gives insights in the achievements of the learners. Assessment can be designed in different ways. While summative assessment evaluates final achievements, formative assessment refers to intermediate evaluation of learning process and an provide feedback that supports the learning. Besides assessment performed by algorithms, a computer can also support self- or peer-assessment. Self-assessment can stimulate reflection on the own performance and it can be used as indicator for personalisation. Peer-assessment is a useful method for collaboration. Computer systems and VLE typically provide tools for conducting these different kinds of assessment.

The construction and procedures of assessments and tests in general have a long tradition in the context of psychology (Crocker & Algina, 1986). There are many different kinds of tests, such as tests to measure or diagnose performance, abilities, personality traits, and psychological disorders. These tests have in common that they typically assess characteristics which are not directly observable. The items of the tests directly measure observable behaviour that are used as indicators for non-observable (latent) person characteristics. Main features of well-constructed tests are validity and reliability, meaning that tests should lead to correct results and same results if repeated. The most prominent test theories are the Classical Test Theory (CTT) and the Item Response Theory (IRT). While the CTT assumes a static relation between assessment item and latent characteristic, IRT makes use of different probabilistic models for such a relation assuming a stochastic relation between observed behaviour (response to the item) and the latent characteristic. A further test theory is the CbKST that assumes prerequisite relations between latent characteristics (see Section 4.3).

A different method of measuring the learner's performance and learning behaviour is called LA. Instead of providing explicit assessment, the data and traces are analysed that originate from the learner's interactions with a computer system without explicit asking for them. The Society for Learning Analytics Research (SOLAR)[1] define LA as *"the measurement, collection, analysis and reporting of data about learners and their contexts, for purposes of understanding and optimizing learning and the environments in which it occurs"*. Siemens (2010)describes LA as *"the use of intelligent data, learner-produced data and analysis models to discover information and social connections, and to predict and advise on learning"*.

LA provides several new possibilities for all stakeholders in a educational system and outside (Nussbaumer, Hillemann, Gütl, & Albert, 2015). New kinds of visualisations and analytic reports can be developed that guide administrative bodies by helping them to improve and allocate resources and to assess the effectiveness of programs, schools, and entire school systems. Advantages fro the learner arise from meaningful visualisations and dashboards that display information

[1] http://solaresearch.org/

of their learning behaviour, progress, and outcome. The captured data can also be used for learning recommendations and personalisation of resources, activities, and people. This way, feedback is provided to the learner, which stimulates self-reflection and motivation.

Technical Infrastructure

Specifications and standards are main features of TEL systems and their components, in order to enable scalability and interoperability (Duval et al., 2017). Content and material used for learning is called learning resources, which includes learning objects and coursewares, but also tools, peers, and descriptions of activities. On the one hand, specifications for content and course packageing are available that structure the content of these resources. On the other hand metadata standards provide uniform descriptions of learning resources. These specifications and metadata makes it possible to reuse learning resources, to share them between systems, and to make them accessible for other systems. Examples are IEEE Learning Object Metadata (LOM)[2] that species learning objects, ADL Shareable Content Object Reference Model (SCORM)[3] that defines course sequences, IMS Learning Design (LD)[4] that allows to model learning processes, IMS Question & Test Interoperability (QTI)[5] that defines assessment items, and IEEE Reusable Competency Definitions (RCD)[6] that defines competences.

For making accessible learning resources over the Internet, repositories are available that store and manage them (Duval et al., 2017). Metadata of the learning resources are used to provide search functionality. In order to have available a critical mass of resources, a distributed architecture can be used. Multiple repositories are connected and a search on an entry point searches a distributed search on all repositories.

Modern TEL systems with manifold features, functionalities, and components make use of many standards and specifications that are typically integrated to coherent framework. For example the Responsive Open Learning Environments (ROLE) interoperability framework consists of specifications of learning tools, communication between the learning tools, tracked learner data, or authentication and single-sign-on (Govaerts, Verbert, et al., 2011). A semantic model defines the key pedagogical constructs (learning activities, competences) and relates them to the learning resources (Dahn et al., 2013).

2.4 Discussion

This section presents an overview of learning concepts, technologies that support learning, and how they can be integrated. First, the historical evolution of technologies for learning is elaborated by listing the major innovations in this field. Second, different psychological theories of learning are presented including design recommendations for learning technologies. Third, a general overview on TEL is given that includes the educational context, approaches that integrate educational with technical concepts, and selected research fields. The main goal of this chapter is to

[2]https://standards.ieee.org/findstds/standard/1484.12.1-2002.html
[3]https://www.adlnet.gov/adl-research/scorm/
[4]http://www.imsglobal.org/learningdesign/
[5]http://www.imsglobal.org/question/
[6]http://www.ieeeltsc.org/working-groups/wg20Comp/wg20rcdfolder/

demonstrate the diversity of TEL. On the one hand it includes research fields such as psychology, pedagogy, computer science, and media technology, and on the other, hand it includes different application fields, such as schools, higher education, the workplace, and the private space of learners. This also leads to different stakeholders – educational researchers, technical researchers, practitioners, administrative bodies of educational institutions, and most importantly learners. Thus TEL targets a whole body stakeholders, technology, and researchers and tries to integrate them.

Such a complexity of TEL leads to many difficulties, problems, and failures. Westera (2010) analysis the historical development of educational technologies in the last hundred years and concludes with a general pattern of failing. In many cases new technologies are introduced with high expectations and enthusiasm. Then it turns out that the technology does not fulfil the educational expectations or is simply not accepted by teachers, learners, or parents. In the end everything stays unchanged and the stakeholders accuse each other of being responsible for this situation. Educational practitioners, educational researchers, and educational technologists have often different goals and intentions. While technologists are enthusiastic about new or complex technology and researchers address new pedagogical methods, the practitioners strive for successful teaching that often exclude the use of frequent change of technology and teaching methods.

The complexity of integrating educational research, technology, and practice increases even more, when considering that the technological developments and societal changes accelerate in our times. Personal devices, technical assistants, virtual reality, artificial intelligence, and much more will find their way into educational applications. Furthermore, the digital revolution pervades our society resulting in the use of computers and smart devices for many social activities. This creates a new context for educational research and technologies and constantly needs changes of existing educational practices and models.

Therefore, it is important to be careful when new technology is introduced into the educational sector. In a meta-study that includes results from millions of students in 50.000 individual studies, Hattie (2009) investigates the effectiveness of 138 influencing factors on the learning outcome. For example, he found out that the use feedback mechanism and meta-cognitive strategies have positive effect on learning. On the other hand, Web-based learning or small classes have little influence. Though the study does not compare combinations of these factors, it is still worth to consider the study results. It provides useful hints on individual learning and teaching techniques, but it also stresses the need for effectiveness in TEL.

While this section presents a broad overview of the role and use of technology for learning, the next two chapters focus on specific topics. The next chapter presents four types VLEs that are commonly used in TEL research and application. Chapter 4 presents three TEL concepts that follow distinct theories for support learning. Both topics form the theoretical basis for the conceptual and technical framework of this thesis.

Chapter 3

Selected Types of Virtual Learning Environments

This chapter presents and discusses four different types of Virtual Learning Environments. The main aims is to outline different approaches of VLEs from a technical and pedagogical perspective. In addition to individual descriptions, the several VLEs are compared to each other, individual strengths and weaknesses are analysed, their features regarding crucial aspects fro learning are elaborated, and their possibilities for combinations or inclusion of new features are presented. These four types of VLEs have been selected and put into focus, because instances of them are used as examples for integrating personalisation support, which one of the main objectives of this work (see Section 5.2).

The chapter also aims at the clarification and definition of the used terms. In literature, the names and terms of learning systems and learning environment systems are used very differently and inconsistently. In this work the term *Virtual Learning Environment* refers to a computer-created or digital learning environment. According to the Glossary of Educational Reform a *Learning environment* (LE) refers to the diverse physical locations, contexts, and cultures in which students learn[1]. This term includes the specific facilities, culture, and social context at the educational institution or learning place, but also the general cultural context. The term VLE is based on this definition, but refers to the space generated by a computer application including the possible tools and features and the social context (peers and communities).

The chapter includes text fragments from own contributions in a peer-reviewed journal publication (Nussbaumer et al., 2014).

3.1 Intelligent Tutoring and Adaptive Systems

There are several definitions of Intelligent Tutoring Systems that partly overlap. Wenger (1987) and Nwana (1990) describe an ITS as a computer program that uses techniques from Artificial Intelligence (AI), in order to create an artificial tutor that knows what to teach, who to teach, and how to teach. The term *intelligent* is explained as computer behaviour that would be described as

[1] http://edglossary.org/learning-environment/

intelligent if performed by a human. More concretely, an ITS is seen as the attempt to produce computer behaviour that would be described as good teaching if performed by a human tutor (Elsom-Cook, 1987). Other terms for the same attempt have been used in the past. Intelligent Computer-Aided Instruction (ICAI) refer to educational software that involve AI, and can be seen as similar to ITS regarding their aims and purposes. Knowledge-Based Tutoring Systems (KBTS) and Adaptive Tutoring Systems (ATS) were used to describe the same type of systems, but without using the term *intelligent*.

Research of ITS is spread over three different research fields, which are computer science, cognitive psychology, and educational research, and lies in their intersection (Nwana, 1990). Thus, ITS research requires a mutual understanding of these disciplines, because of their different research goals, terminologies, and theoretical frameworks. The motivation for ITS research is motivated by both research and practical needs (Elsom-Cook, 1987). Research needs stem from the intersection of the three fields, which provide testbeds for their theories. For example, psychological theories can be tried out by using computer in educational settings. Practical needs arise from the fact that artificial tutors can be used in ways that is not possible for human tutors fro social and economical reasons. For example, one-to-one tutoring cannot be provided for everybody, though private tutoring leads to better learning results than classroom tutoring (Bloom, 1984).

Though there are many different approaches for ITS architectures and concepts, key components can be identified. Nwana (1990) presents the typical modules of an ITS in a general architecture (see Figure 3.1). These modules are the (a) expert knowledge module, the (b) student model module, (c) the tutoring module, and (d) the user interface module. The expert knowledge module comprises the facts and rules to be conveyed to the student. Facts and rules are explicitly represented in the system and represent the knowledge of the teacher in a certain domain. The student model module takes care for the representation of the student's knowledge and skills. This information is dynamically changing in the learning process when students increase their knowledge and skills. The tutoring module is responsible for the teaching (or pedagogical) strategy and is closely linked to the expert knowledge and student model module. The user interface module enables the interaction of the student with the system by translating between internal representations of the system and a language understandable to humans.

A general workflow of an ITS is described by V. J. Shute and Psotka (1996) who put these components in relation. An overview of their view on ITS is depicted in Figure 3.2. The basic assumption of this workflow is that a student learns by solving problems which the ITS iteratively and adaptively presents to the learner fitting to the current knowledge. Consequently the workflow starts with the selection of a problem to be solved by the student. The selection is performed by the tutoring component that takes into account the curriculum information and student model information. The curriculum contains what should be learned and the student model holds the information what the learner already knows. Then the system compares the answer of the student with its own solution to the problem and performs a diagnoses on the differences between them. Feedback is provided to the student based on the result of the comparison and when the last feedback was provided. Finally, the user model is updated and the loop is re-iterated.

Research and development on ITS has a long tradition of at least 30 years with a variety of specific approaches and goals (V. J. Shute & Psotka, 1996). In the 70s systems were created that focused on automatic problem generation and developed basic elements of classic ITS. For exam-

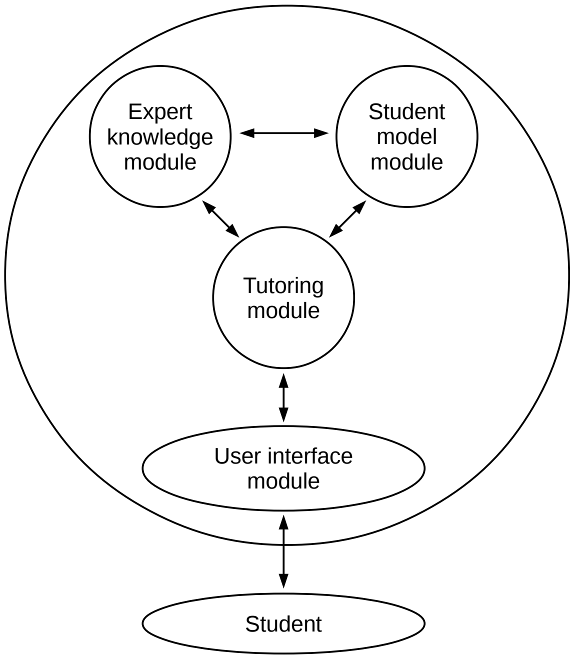


Figure 3.1: This diagram depicts a general ITS architecture (picture taken from from Nwana (1990)).

ple, *student modelling* was employed by the Basic Instructional Program (BIP) where a method for learning the computer language BASIC was developed that relies on the required skills and a meaningful sequence how they should be learned (Barr, Beard, & Atkinson, 1976). *Knowledge representation* was initially developed in the SCHOLAR program where a semantic net represents the domain knowledge Carbonell (1970). The student model in the program was realised through the network nodes that represented the concepts to be learned and stored the information whether the student knows the respective concept. The *tutoring strategies* of these two examples was built around a strategy which (unknown) skill or concept should be learned next. Thus problems could be selected and presented iteratively and adaptively to the student. Other tutoring approaches were based on rule-based expert systems, such as MYCIN, a system for diagnosing meningitis that compared student questions with pre-defined questions (Shortliffe, 1976). *Reactive learning environments* responded to the learners in a variety of ways to support their understanding. For example, SOPHIE (Sophisticated Instructional Environment) allowed students to ask various questions to obtain measurement values of simulated broken electrical devices, in order to develop troubleshooting skills (Brown & Burton, 1975).

A decade later, Sleeman (1984) outlined four main research areas, in order to address the main problems of the early ITS:

1. Instructional feedback for a learner was often on detailed enough
2. Systems forced the learner into their own conceptual framework instead of adapting to the learner
3. Tutoring strategies lacked of theoretical cognitive foundations
4. User interactions and exploration was too restrictive

These concerns were addressed by a plethora of systems and approaches that were developed in the 80s. *Model tracing* was developed as an approach that uses production rules to model

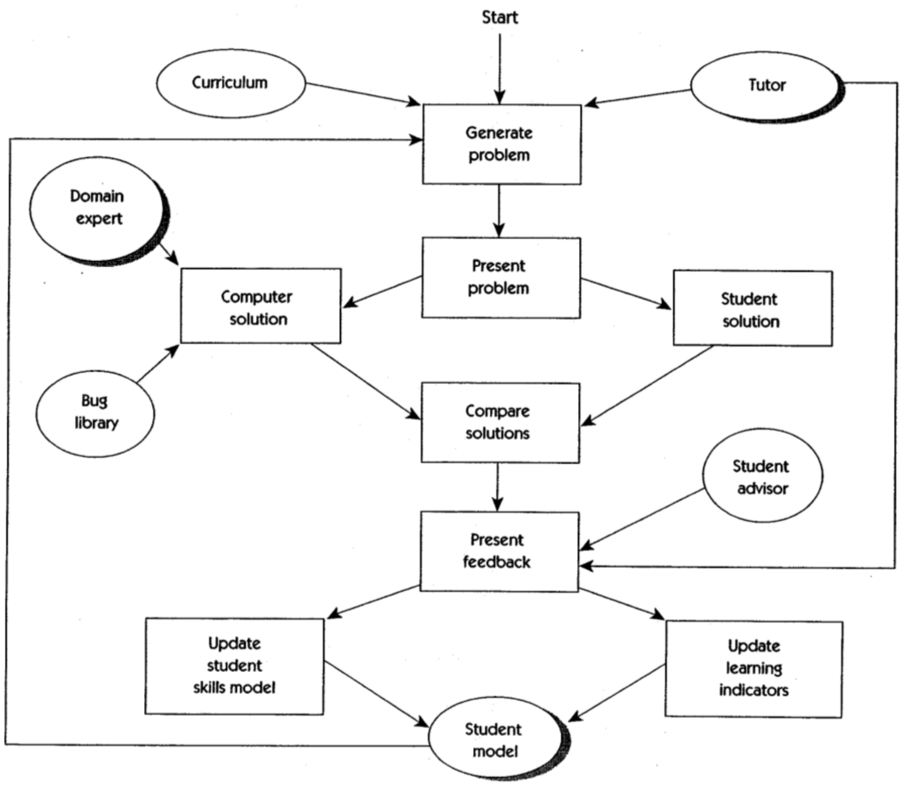


Figure 3.2: This diagram depicts a general ITS procedure (picture taken from from V. J. Shute and Psotka (1996)).

cognitive skills and thus human behaviour on a detailed granularity level. This allows the constant monitoring of the acquisition of the cognitive skills, which results in immediate feedback if deviations from the learning path are detected. This approach was developed in the context of Anderson's advanced computing tutoring theory ACT (later ACT-R), a framework that models cognitive processes. Applications based on this approach are called cognitive tutors, for example the LISP tutor (J. R. Anderson, Corbett, Koedinger, & Pelletier, 1995). This approach addressed the Sleeman's first three research areas, as it gives detailed feedback, adapted to the learners conceptualisations, and is based on a cognitive theory. However, it does not give freedom to the learner (V. J. Shute & Psotka, 1996). *Discovery worlds* were an approach that addressed the forth research area by allowing the learner to explore a topic in simulated micro-worlds and got implicit and rather natural feedback (e.g. exploring Newton's laws White (1984)).

Adaptive educational hypermedia systems are a special case of ITS, as they evolved as a combination of educational hypermedia and ITS (Brusilovsky, 2000). Traditional hypermedia systems make accessible a inter-linked documents in a static way. In educational adaptive hypermedia systems these documents contain learning content. While educational hypermedia systems follow a one-size-fits-all approach and provide the same content and navigation for each user, adaptive educational hypermedia systems dynamically adapt to the goals, preferences, and knowledge of the learner. Adaptation is achieved by altering the the content (adaptive presentation) or altering the links between the document (adaptive navigation). Adaptive presentation can be realised by hiding or highlighting specific parts of a document and adaptive navigation can be achieved by hiding, highlighting or annotating links between the documents.

A prominent example of an educational adaptive hypermedia system is the Adaptive Hypermedia Architecture (AHA!) (De Bra et al., 2003). This approach makes use of the core elements of an ITS, which include a domain model, a user model, and an adaptation (tutoring) model. The domain model consists of a set of concepts that represent a subject domain. The concepts are inter-linked and form a network (concept map), and also are linked to Web pages. Each concept has a set of attributes that are the basis for the user model. Attributes, such as *visited* or *interest* can be used to store information about the user, if a user has visited this concept and related page or if a user is interested to learn this concept. Adaptation rules define how the concept attributes are updated taking into account the user behaviour that triggers the rule (condition) and the calculation that is applied on the attributes (action). Furthermore, the adaptive presentation and adaptive adaptation rules define how the user model attributes are exploited, in order to adapt the system to the learner. The general architecture of AHA! is depicted in Figure 3.3. This architecture contains a component that holds domain and user model, an adaptive engine that applies the adaptation rules, external Web pages, and an authoring component for creating the models and rules.

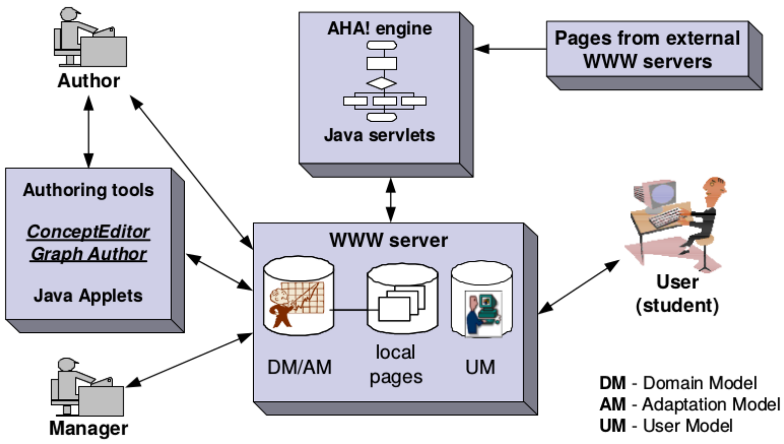


Figure 3.3: This picture gives an overview of the AHA! architecture (picture taken from from De Bra et al. (2003)).

3.2 Learning Management Systems

In educational institutions Learning Management Systems (LMS) have become very popular and are used in many universities and schools (Kalz, Schön, Linder, Roth, & Baumgartner, 2010; Paulsen, 2003). They assist teachers and tutors in their organisation and distribution of learning content. Typically, LMS are easy to use and are in line with the structures and organisation of classical educational institutions. Examples of LMSs are Moodle[2], Sakai[3], ILIAS[4], .LRN[5], or Blackboard[6]. They all have in common, that different tools are integrated in a single system, such as discussion forums, file sharing, whiteboards, chat, and e-portfolios Dalsgaard (2006).

Compared to Intelligent Tutoring Systems, LMSs are a different type of educational computer

[2]http://moodle.org/
[3]https://www.sakaiproject.org/
[4]http://www.ilias.de/
[5]http://www.dotlrn.org/
[6]http://www.blackboard.com/learning-management-system/blackboard-learn.aspx

software. Watson and Watson (2007) define an LMS as the infrastructure that delivers and manages learning content, identifies and assesses individual and organisational learning or training goals, tracks the progress towards meeting those goals, and collects and presents data for supervising the learning process of an organisation as a whole. In addition, an LMS handles course registration and administration, skills gap analysis, tracking and reporting.

Watson and Watson (2007) also distinguishes the term LMS from other terms that are often used synonymously or that are mismatched. According to them a Course Management System (CMS) is a system that allow the creation of a course content and the teaching and management of that course with respective student interactions. However, a CMS does not include the full and systematic functionality of an LMS, but is rather a subset of an LMS. A Learning Content Management System (LCMS) focuses on creating, managing, delivering, and reusing learning content. However, it does not target the learner and the whole educational organisation. To some extent a LCMS and a LMS have complementary functionalists. While a LCMS allows the creation of learning content, the LMS uses the learning content and takes care for the whole learning process in an organisation.

In order to clarify the nature of an LMS, Watson and Watson (2007) list a set of functional requirements for a corporate LMS. These requirements are in line with the definition of an LMS given above. They outline that the LMS should be able to manage not only the learning content, but whole learning process in an educational institution:

- enable integration with the human resources system
- enable the administration of content, tutors, learners, schedules, and budget
- provide access to content delivery
- allow to develop content, including authoring, maintaining and storing
- integrate content with third-party courseware
- assess learners' competency gaps and manage skills acquisition and status
- provide and support authoring of assessments
- adhere to content standards (such as SCORM) which allow for importing content and courseware
- support configuration of the LMS to function with existing systems and internal processes
- provide security such as passwords and encryption

A similar point of view on LMS is given by Kalz et al. (2010), who characterise an LMS as a system that consists of three main components: Administration, Communication, and Content. In addition to the definition above, the communication aspect plays an important role in their view. These components include the following functionalities:

- Administration: tools for user management, course management, statistics, evaluation, etc.
- Communication: tools for tutors and students to communicate with each other
- Content: tools for course delivery, assessment, glossary, etc.

The importance of communication and collaboration features in a LMS is emphasised by Dalsgaard (2006). In addition to content organisation and knowledge transfer, communication and collaboration tools enable students to work together on a shared problem. For example, students could use a forum for discussing a problem, a wiki for working together on a task, or file sharing for exchanging information. These are important features, because collaboration has positive effect on the engagement and motivation of students.

Modern LMSs are designed as systems with a modular architecture with a plug-in structure (Jabr & Al-Omari, 2010). This allows the development and integration of new modules and tools. Hence, such LMSs can be extended and adapted to the needs of the educational institution. In many cases they follow an service-oriented architecture (SOA), which allows the encapsulation of functionalities. Furthermore, SCORM has widely been accepted as standard for content model, which makes it possible to share and re-use content with other installations and systems. An example of a LMS architecture is depicted in Figure 3.4. This diagram shows the modular approach of Moodle with individual layers for the user interface, the module functionalities, and information storage layer.

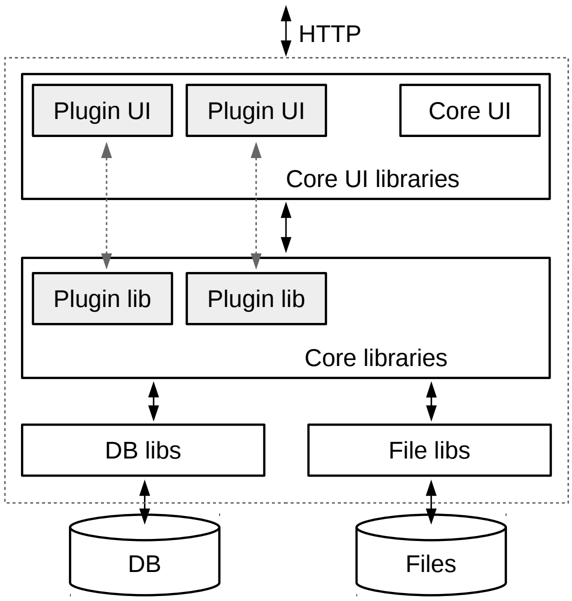


Figure 3.4: This picture shows an overview of the Moodle architecture.

3.3 Personal Learning Environments

This section includes text fragments from own contributions in a peer-reviewed journal publication (Nussbaumer et al., 2014).

In contrast to an LMS, a Personal Learning Environment (PLE) strives for a more natural and learner-centric approach. A PLE can be characterised as a computer application that allows the learner to create an individual learning environment. While a LMS is course-centric and inflexible for the learner, a PLE enables the learner assemble an environment that meets the own needs, goals, and preferences. The ingredients for such a learning environment include different types of resources, which are content, tools, and people. In principle, this can lead to similar learning environments as LMS. However, LMSs are pre-designed by teachers or tutors and the same setting is deployed to all students. A PLE is a container that provides enough flexibility and freedom to the learner, in order to empower the learner to create a personal environment.

This paradigm shift has several consequences, that are outlined by Wilson et al. (2007) and Schaffert and Hilzensauer (2008). The most important are summarised in the following list:

1. A new type of personalisation. Traditionally personalisation is connoted with the adaptivity of an ITS, where the system adapts to the learner. Personalisation in the context of a PLE puts the learner in control who builds and adapts the system and learning process to the own needs and preferences.
2. Social involvement and the role of community. In addition to collaboration tools used in LMSs, PLEs integrate the involvement of people as resources and whole learning communities on a conceptual level. For example, people can be recommended as learning peers or learners can join a community.
3. Ownership and protection of learner's data. A PLE does not only give control to the learner regarding the creation of the learning environment, but also gives access to the own data.
4. Symmetric relationships. In the context of an LMS the learner is more or less a consumer of learning resources. However, a learner who uses a PLE is also a produces of resources, such as the PLE encourages to create and share content, information of used tools, and contacts to peers.
5. Open Internet standards and APIs. As PLEs encourage the exchange and integration of resources available on the Web, standards or at least well-documented APIs are needed that allow the transfer of resources and information of resources.

There is a debate, if a PLE is a system, an enabling technology, or a design concept (Fiedler & Väljataga, 2011). Educational researchers and practitioners tend to focus on the overall re-organisation of the core activities in educational institutions. Thus they reflect the pedagogical potential of PLEs and take a conceptual point of view on PLEs. On the other hand, computer scientists and technology providers focus on the new technical opportunities and focus on the enabling technology and resulting computer systems. In the following, examples of PLEs are shortly described.

An example based on social media tools is eMUSE (Popescu & Cioiu, 2011), which integrates Web 2.0 tools into a single system. It claims that such tool integration leads to a sense of community and thus increases success and retention rates. Furthermore, eMUSE offers support for self-monitoring and self-evaluation by providing feedback on learning tasks, which is supposed to increase learning success and motivation. A shortcoming of eMUSE is that it allows instructors to create such settings of tools and does not give learners the freedom of selecting tools and personalising their environment.

A further example is the PLE developed at the Graz University of Technology (Ebner & Taraghi, 2010). This PLE allows for selecting widgets from a repository and adding them to a personal space. Beside some general purpose widgets (similar to the tools in an LMS), domain-specific widgets have been created by students in university courses. It also allows for logging students' activities performed on these PLEs. A drawback of this PLE is the missing pedagogical support for selecting widgets. In the course of a study (Softic et al., 2013), a semantic model has been created to analyse the activities and display them on a dashboard. This study revealed that the teacher is no longer the provider of knowledge, but rather a mediator between knowledge and student. On the other side, the student is responsible for organising information and own learning.

The Graasp system Bogdanov et al. (2012) allows users to create their own PLEs consisting of people, spaces, assets, and tools. In addition, it also provides an activity model to describe the learning tasks. One of the aims is the support for sharing resources among learners, for example they can share the tools and assets they use. Graasp also offers a repository of widgets (or tools) that can be added to the personal environment. Moreover, Graasp provides an infrastructure for the creation of recommendation strategies through an interface for retrieving learner data.

Another approach is the augmentation of traditional LMSs with widgets, in order to make an LMS more flexible. Such an implementation is described in Wilson, Sharples, Popat, and Griffiths (2009), where Moodle has been modified to support the integration of widgets from a repository. The difficulty with this approach is the lack of communication between Moodle and the widgets. So the integration is done only on the level of the user interface, but not on the level of learner information integration.

On a theoretical level a general approach is described in Wild, Moedritscher, and Sigurdarson (2011). The authors call this approach a mash-up personal learning environment (MUPPLE) and regard it as a vision of the future of personalised, networked, and collaborative learning. One of the statement is that a learning environment is not only created on a technical level, but it consists of a network of people, artefacts and tools centred around learning activities that are performed towards a previously defined learning outcome. This approach is also demonstrated with a prototypical implementation and a concrete scenario.

In order to provide specific support for learners, there are some approaches and implementations of recommendation strategies available. ReMashed Drachsler et al. (2009), a system that follows the MUPPLE design, provides recommendation of Web 2.0 resources. Learners can personalise emerging information of a community can rate information of the Web2.0 sources. Based on this user-generated information and collaborative filtering mechanisms, ReMashed offers tailored recommendation to the learner. A similar approach done by the Binocs widget Govaerts, El Helou, Duval, and Gillet (2011) that uses a federated search engine in the background and makes recommendations for learning resources (learning objects) based on social tagging.

A different recommendation approach is described in Lachmann and Kiefel (2012). In contrast to providing learning resources on content level, this approach is based on a model that recommends learning activities based on a taxonomy of cognitive and meta-cognitive learning activities. The learner selects recommended activities and based on these choices new recommendations are generated. This approach is supposed as help for especially weak learners to guide them through the learning process. A more complex approach is the 3A model El-Helou, Salzmann, and Gillet (2010), that provides recommendations based on actors (users or agents), (individual or collaborative) activities, and assets (Web resources) in a PLE. Collaborative filtering and page rank strategies are used to recommend these entities.

3.4 Virtual Reality Learning Environments

In this work we understand a Virtual Reality Learning Environment (VRLE) as a learning environment that is facilitated by virtual reality technology in all its variants and and with all its possibilities. Before dealing with the VRLEs, the VR concept and technology is examined.

Virtual reality (VR) is a (mostly) three-dimensional simulation of a physical environment that a human can see, browse, and interact with in real-time. Though there are a lot of different definitions of VR available in literature, in this work we prefer a simplified definition that does not rely on any specific technology or manifestation. On the one hand there are also references to text-based and two-dimensional VR concepts and applications. Examples for text-based VR systems are multi-user online applications that give access to virtual shared rooms simulated through a text-based interface (Curtis & Nichols, 1994). Two-dimensional visual interfaces can also provide access to simulated reality and are precursors of 3D VR systems.

In order to realise a VR application, a visualisation and an interaction device is needed (Vergara, Rubio, & Lorenzo, 2017). Depending on the specific technology, a range of applications with different degrees of complexity and and immersion created. The visualisation device can be a an ordinary computer monitor, a head-mounted display (HMD), or a cubic immersive room with displays on each side (CAVE). Analogously, the interaction device can be a traditional computer keyboard and mouse, a specific interaction device that is spatially tracked (e.g. data glove), or the body of the user who's movements are spatially tracked. In this way different types of VR applications can be created, ranging from a ordinary computer with perspective visualisation of a physical world or object to a setting where a user wearing a HMD who interacts with a data glove and who's movement in the physical space are tracked.

A more abstract definition of a virtual reality environment is given by Blascovich et al. (2002), who defines it as "synthetic sensory information that leads to perceptions of environments and their contents as if they were not synthetic". This definition also includes other human sensory channels for the interactions with the VR application, such as auditory, haptic, or olfactory sense. These forms of interactions make the experience of the virtual reality environment more realistic, but also need more complex technology, such as devices for haptic feedback. A similar definition is given by Schroeder (2008) who define virtual environment and virtual reality as "a computer-generated display that allows or compels the user (or users) to have a sense of being present in an environment other than the one they are actually in, and to interact with that environment".

In addition to the basic definition of VR technologies, several features determine how they can be used and what can be done with them. Some of the most important features are outlined in the following list:

- Immersion. An immersive VR environment denotes a setting where the user is more or less completely surrounded by VR environment. For example, the use of a HMD, a haptic data glove, and earphones induces a high degree of immersions. Immersion, in general refers to the feeling of presence with the content, context, and objectives. This is also achieved with narratives, stories, and games without VR environments or in combination with them.
- Content dynamics. Content can consist of static 3D objects, but also of dynamic objects that include scripts for facilitating animation or interaction with the user. Interactive 3D objects provides a more complex experience for the user.
- User-created content. Following the Web 2.0 paradigm, some VREs provide the possibility for the user to create own content. Instead of a VRE with pre-defined content, this feature makes it very flexible and natural.
- Multi-user support. A VRE with multi-user allows many users to discover the same VRE. Typically, users are represented as avatars and can communicate with each other. This implies a technology that allows users to login to the VRE over the Internet.

Especially the multi-user support leads to another term often used in this context: Virtual

World (VW). Schroeder (2008) defines a VWs as shared virtual environments that are persistent online spaces with large populations and where users can interact, collaborate, and socialise with each other. In contrast to text-based communication, interactions in VWs are more complex and non-verbal, and thus more natural. In combination with the Web 2.0 paradigm where users can create the 3D content, VWs become truly powerful and dynamic spaces with many possibilities to collaborate on content or to build own places and applications.

In the last decades, virtual reality has been applied in many fields of research, science, engineering, medicine, entertainment, and education. For example, in engineering 3D models of engines or machines can be created as part of a more sophisticated form of virtual prototyping, in medicine virtual models of the human body can be used to teach anatomy, or games can be applied in 3D space to make them more realistic. In this work we focus on the possibilities and applications of learning environments that are facilitated by the VR technology. A recent NMC Horizon Report (L. Johnson et al., 2016) emphasises the relevance and positive impact of virtual reality for education. Examples mentioned in this report are STEM disciplines (science, technology, engineering, mathematics) to prepare students for the future workplace, online learning to facilitate group learning of geographically distant students, and medicine for surgery training.

The reason for the positive affect of VR on learning are specific features and opportunities of VR. In literature they are seen as affordance that stimulate certain kinds of learning, which is evoked through a relationship between features of a system or environment and characteristics of a learner (Dalgarno & Lee, 2010). Some of these affordance are listed by Bailenson et al. (2008) and Dalgarno and Lee (2010):

- Learning tasks can be designed that make use of enhanced spatial knowledge representation of the explored domain. For example, parts of the human body or machines can be spatially visualised.
- Experimentation learning tasks can be designed that would be impractical or impossible to undertake in the real world or in 2D learning environments. For example, students can do physics experiments with visualisations of magnetic fields.
- A VR environment can provide realistic contexts, which supports learning according to constructivist learning theory.
- Learning tasks can be designed in a way that increase the intrinsic motivation and engagement of the student. For example, abstract information or simulations can be made visible and concrete, which supports the understanding of the learner. Furthermore, learners can feel more present at an experiment than typical in real-world experiments.
- Learning tasks can be designed that lead to improved transfer of knowledge and skills to real situations through contextualisation of learning. For example, language learning can take place in virtual locations fitting to the current topic.
- VRLEs can be used to facilitate tasks that lead to richer and more effective collaborative learning not possible with 2D environments. For example, non-verbal communication facilitated through the avatar representation of peers provides additional information to the learners.
- Simulation of dangerous or expensive lessons can be made possible in a way that is not feasible in real-worlds.
- Advanced monitoring and tracking of user behaviour is possible in VRLEs, as richer inter-

actions are possible than in 2D learning environments. Tracking data can be used for better learner profiles leading to new personalisation opportunities.

Currently, numerous applications of VRLEs have been implemented and tested. For example, at Case Western Reserve University, in partnership with Cleveland Clinic, a holographic medical anatomy curriculum for the Microsoft HoloLens has been developed. This curriculum features a library of 3D holographic human models that provide view on the human anatomy which is nearly impossible for students to experience through traditional dissection or with medical illustrations (L. Johnson et al., 2016).

Other examples can be found in connection with SecondLife, a commercial virtual world application. SecondLife offers many features of VR environments described above, such as multi-user support and user-created content. Genome Island is a virtual laboratory environment where undergraduate students can learn genetics. This laboratory is organised as an exhibition of more than fifty activities that teach different aspects of genetics (Clark, 2009). For example, one object of this exhibition is a cell with the "genetic interior" that the user can view and explore.

A similar objective is pursued by Maroon VR that features a three-dimensional virtual laboratory with physics experiments (Pirker et al., 2017). This laboratory includes interactive experiments with electric and magnetic fields that are made visible and tangible to the user. For example, an experiment realises the Van de Graaff generator that creates high electric potentials between two metal globes (see Figure 3.5). Maroon VR is implemented with Unity3D[7] and deployed for the HTC Vive[8] and a cheaper mobile VR version with Gear VR[9].

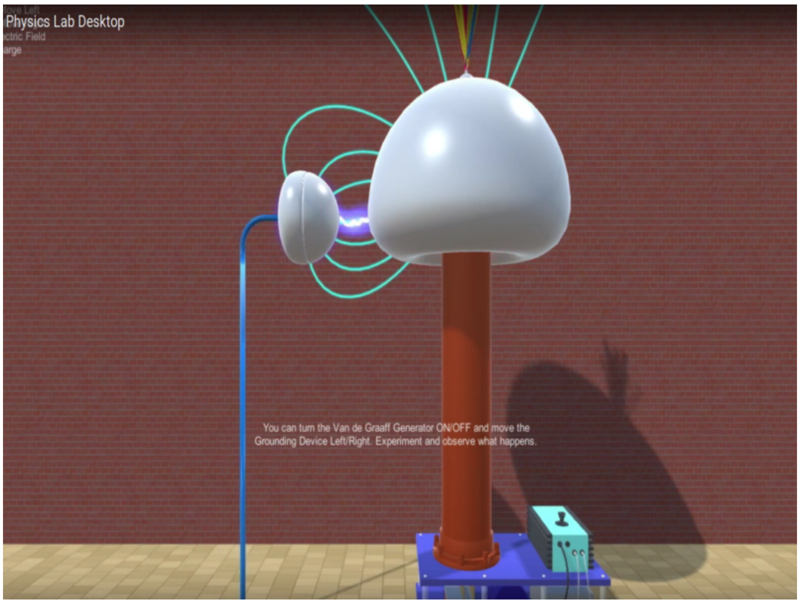


Figure 3.5: Van de Graaf Experiment in Maroon VR (Pirker et al., 2017).

[7]http://www.unity3d.com
[8]https://www.htcvive.com/
[9]http://www.samsung.com/global/galaxy/gear-vr/

3.5 Discussion

This section presents for types of learning environments that are realised with computer applications. One of the aim of this section is the clarification and definition of each learning environments and according names. In this work these learning environments (and all learning environments facilitated by computers) are subsumed as *Virtual Learning Environments* (VLE). In literature the term Virtual Learning Environment is also applied on Learning Management Systems, as well as on Virtual Reality Learning Environments.

The four types of VLEs have been described in a way that they can be distinguished from each other. Several initiatives were undertaken where these VLE types have been used in combination or where typical features on one VLE type has been added to another VLE type. In the following some examples are given.

- Livingstone and Kemp (2008) introduce a VLE approach that integrates SecondLife with Moodle and named it *Sloodle*. It mimics the structure of a Moodle course with 3D objects in SecondLife. When the course designer re-positions web content blocks, the corresponding 3D objects are automatically re-positioned. It is interesting to see the use of SecondLife as a learning environment and the use of virtual objects specific for learning.
- Another combination of two VLE types can be found in several initiatives where Moodle has been combined with PLEs. Such initiatives aimed at bringing in personalisation and autonomy of the learner into course-based LMS structures. In order to realise such an approach, Moodle plugins have been developed that integrate PLE functionality. For example, such a Moodle plugin is able to allow the leaner to create personal spaces consisting of tools that are included by the learner (Mikroyannidis & Connolly, 2015).
- As described above, LMSs are course-centric and have almost no inherent adaptivity functionality. In order to enrich a LMS with adaptivity, several developments have been conducted in this direction. An example is described by Graf, Kinshuk, and Ives (2010), who describe an approach where Moodle is enriched with adaptivity to support learning styles. Based on individual learning preferences, learning objects are highlighted through adaptive sorting and adaptive annotation.
- Further approaches have been developed that integrate adaptivity and intelligent tutoring into LMSs. The research project GRAPPLE developed an adaptive learning environment that employed generic adaptivity rules and concepts. The adaptivity features including user models were made available in Moodle (De Bra et al., 2013). Another approach has been undertaken to integrate intelligent tutoring with any LMS (Giuffra Palomino, Azambuja Silveira, & Nakayama, 2014).

In order to compare and evaluate the individual LE types, they can be considered in the light of crucial aspects, such as support for competence development, adaptation, self-personalisation, and use in educational institutions. An overview is given in Table 3.1.

- Competence development as is primarily targeted by ITSs, as they have knowledge or competence models that serve as basis for the tutoring strategy. The other VLEs support competence development to some extend, but rather implicitly. LMSs partially have competence lists associated with courses and learning objects. PLEs and VRLEs partially provide learning tasks that are created with the goal to improve certain competences.

- Adaptation is the core feature of ITS. The other LEs usually do not have included adaptation functionality by default, but allow the integration or extension of such a feature. In many cases this is realised through recommendation or feedback approaches.
- Self-personalisation is the key feature of PLEs, but also VRLEs support the possibility to let the user personalise the system. ITSs and LMSs typically do not allow self-personalisation
- The use in educational institutions primarily focuses on LMSs. The use of ITSs and PLEs is rather on a experimental level, if used in an educational system. VRLEs have a great potential to be more included in the future.

Table 3.1: Overview of the VLE types regarding crucial aspects

	ITS	LMS	PLE	VRLE
Competence	+	o	o	o
Adaptation	+	-	o	o
Self-Personalisation	-	-	+	+
Educational Institution	-	+	-	o

The consideration of the VLE types regarding the crucial aspects also outlines the advantages and disadvantages, strengths and weaknesses of each VLE type. ITS have great features to guide a student through a course and adapt the course to the knowledge and learning history of the student. However, the creation of such tutoring strategies and related domains are expensive and specific for each domain, which also makes the inflexible regarding other pedagogical strategies. LMS have their advantages that they adhere to the structures of the educational institutions. Furthermore they are have little complexity and are easy to use. However, they follow a one-size-fits-all approach and do not respect individual preferences of the students. PLEs give a lot of freedom to the learners, support collaboration and communities, and stimulate motivation. However, they they also bear the danger, that students who can deal with free choices can get lost in such situations. So there is a need for to support features for weak learners who need structures and directions in their learning process. Finally, VRLEs have their strengths in their 3D visualisations of learning content and their possibilities for collaboration. Similar to PLEs, students to need structures and directions must be provided with recommendations or other types of learning support.

Following the analysis of the individual VLEs, it becomes clear that combinations of different types of VLEs or core features of them bring advantages and are often needed. A major goal of this work is the design of a concept that enriches VLEs with adaptation and personalisation features and to facilitate learning based on competence models. Though other initiatives in this direction exist (e.g. De Bra et al. (2013)), this concept integrates a combination of psychological and pedagogical theories (competence-based learning and self-regulated learning).

Chapter 4

Selected Learning Concepts

In this chapter three learning concepts are described that have strongly influenced TEL systems. Each concept is described from a theoretical and practical perspective. The theoretical perspective presents the underlying psychological and pedagogical background, as well as its main concepts. The practical perspective lists some examples where these approaches have been applied. Furthermore, the three approaches are discussed regarding essential learning aspects and how they are interrelated.

These three learning concepts have been selected, because they are essential for this work. An integrated approach is elaborated that consists of the main features of these learning concepts (see Section 5.2). The goal of this section is to provide a conceptual and theoretical basis for the integrated approach by analysing the related work.

The chapter includes text fragments from own contributions in peer-reviewed journal and conference publications (Albert, Hockemeyer, Kickmeier-Rust, Nussbaumer, & Steiner, 2012; Nussbaumer, Dahn, Kroop, Mikroyannidis, & Albert, 2015; Nussbaumer et al., 2014; Nussbaumer, Gütl, & Albert, 2007; Steiner, Nussbaumer, & Albert, 2009).

4.1 Personalisation and Adaptation

This section gives an overview of personalisation and adaptation in the context of TEL. It focuses on the main concepts how adaptation and personalisation is achieved and which models are needed for this aim. Despite the existence of different kinds of adaptive systems for learning (for example in games), the scope of this elaboration is restricted to Adaptive Educational Hypermedia (AEH).

4.1.1 Theory and Concepts

Taking into account the learner's characteristics by individually adapting learning methods has a big influence on the learner's performance (Issing, 2002). The importance of *adaptation* to the learner's characteristics (also called *personalisation*) was shown in several studies. For example, the adaptive subject material combined with adaptive styles of presentation supports students to improve their learning achievements and increases learning efficiency (Tseng, Chu, Hwang,

& Tsai, 2008). Furthermore, the importance of adaption to individual learning preferences of a learner regarding visualisation and verbalisation has been proven (Plass, 1998). Through a requirement analysis it has been found out that the learner's knowledge, goals and tasks, language, interests, and learning styles are important factors of personalisation approaches (Höver & Steiner, 2009).

In an early article about adaptive hypermedia (AH), Brusilovsky (1996) gives a seminal overview of methods and possible *application areas* of adaptive hypermedia. Besides online information systems, online help systems, and information retrieval systems, he considers educational hypermedia (EAH) systems as the most popular ones. Basically, in educational adaptive hypermedia the learning material or course of a particular subject is represented by a relatively small hyperspace. Within this setting, he describes two problems that can be solved with adaptive hypermedia. First, knowledge of different users can vary significantly and can grow differently. Second, entering a hypermedia course, learners can start with too difficult pages and can get lost in hyperspace. Both problem can be solved with navigational help provided by adaptive hypermedia systems. The *adaptation goals* define why adaptation is applied and which problems of the users should be solved. This depends on the application area, because each of them have their own problems to be solved.

While the adaptation area and the adaptation goal form the context of an AEH, Brusilovsky (1996) lists three dimensions that characterise AEH systems and that can be used to classify and evaluate them. First, *adaptation methods and techniques* for adaptive hypermedia define how the adaptation takes place. Adaptation techniques are related to the implementation level and characterise by the kind of knowledge representation and adaptation algorithm. Adaptation methods are the generalisations of the adaptation techniques and consist of the adaptation ideas on a conceptual level. Both explain how the adaptation should be done. Second, the *features of the system to be changed* define what should be adapted. This includes the content (adaptive presentation) and the navigational possibilities (adaptive navigation support). Third, the *features of the users* to be taken into account define to what the adaptation should be made. These features include the knowledge, preferences, goal, of the users. These three dimensions (what, how, and to what should be adapted) together with the context (where and why should be adapted) build one of the first classification model of EAH systems. An overview of the this conceptual approach is depicted in Figure 4.1.

A similar approach on adaptive e-learning is presented by V. Shute and Towle (2003). This article presents a concept for adaptive e-learning based on Aptitude–Treatment Interaction (ATI) research (Cronbach & Snow, 1977). ATI research is a psychological approach to investigate the relations between individual differences of learners and learning environments. Such relations are called aptitude–treatment interactions, where aptitude refers to the personal traits and knowledge of a learner and treatment refers to the features and conditions of the learning environment. The goal of ATI research is to discover which learner characteristics can be used to select the best learning environment for a particular student to increase the learning outcome. While this research targeted "real" (non-digital) environments, later research also investigated ATIs in computer-based environments Maki and Maki (2002). The rational behind ATI research is, that by mapping personal traits or characteristics to learning environments and instructional components, educational instructions and settings could be customised to any given learner.

Based on ATI research (V. Shute & Towle, 2003) derives the components for adaptive e-

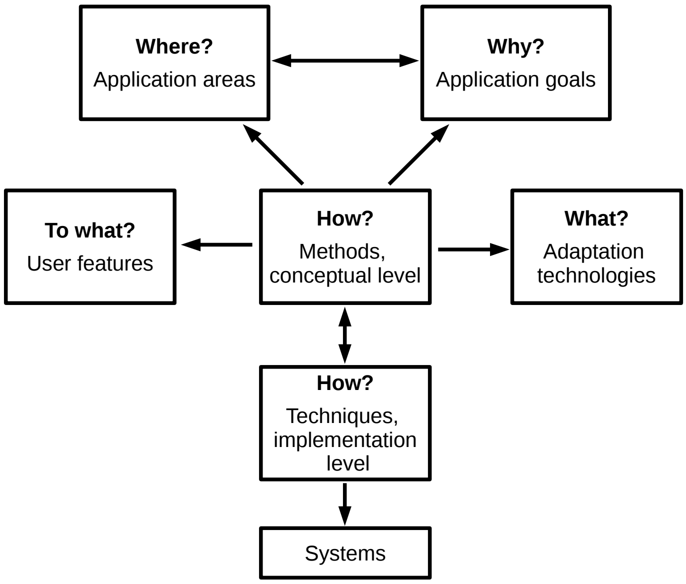


Figure 4.1: This picture shows the general adaptation concepts from Brusilovsky (1996).

learning and presents a framework for a learning management system with adaptive features (see Figure 4.2). The core components of this framework are the content model, the learner model, the tutoring model, and the adaptive engine. The content model consists of the subject domain to be learned and assessed including its structures and interdependences. It is a requirement for adaptive systems that the content model is flexible enough, in order to allow the adaptive presentation of individual bits of knowledge. Thus, Shute and Towle split the content model into two parts, which are learning objects and knowledge structures. While learning objects are small reusable components that contain pieces of content to be presented to the learner, knowledge structures consist of conceptual knowledge that refers to the learning objects and interlinks them. The learner model consists of the learners' individual features and knowledge, while the knowledge is in relation to the content model. The tutoring model manages the presentation of the content based on the learner model with the goal of prescribing the optimal learning path for the individual learner.

The adaptive engine uses information from these three models and facilitates adaptive learning. The main task of the adaptive engine is to select a learning object to be presented next. In this way a sequence of learning objects is assembled to a learning path. The selection strategy is based on the learner model and the rules of the tutoring model. The learner model contains the current knowledge of the learner and other person information, such as personality traits. An assessment is undertaken to obtain pre-knowledge and person information. The adaptation rules control the selection of the adaptive engine. They take into account the learner knowledge, the information which learning object has been visited so far, the content model with the interdependences between the learning objects. The instructional rule have further effect on the content selection by following pedagogical strategies.

[### A paragraph on domain models, user models, and overlay models] Brusilovsky and Millán (2007)

A newer trend are OLMs that follow the idea of opening up the models used by adaptive systems and making their information visible for the user (Bull & Kay, 2010). OLMs make adaptive

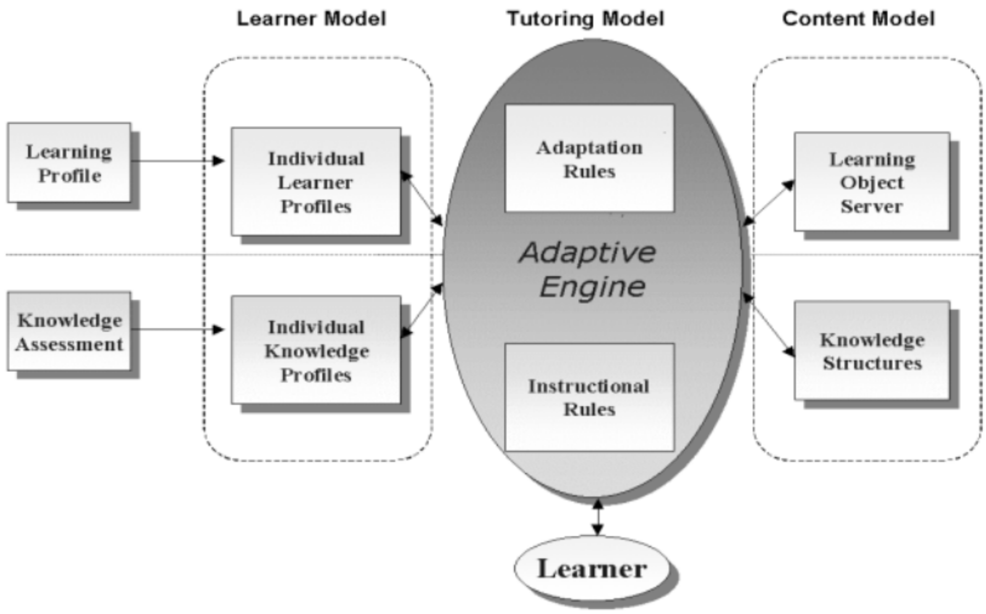


Figure 4.2: Concept and components of an adaptive system from V. Shute and Towle (2003).

systems scrutable and inspectable, as they allow the user access to the information that is used to generate adaptation. The rationale behind this approach is to provide formative feedback that supports and stimulates the learner's reflection process. This is supposed to lead to deeper understanding and increased motivation (see also Section 4.2). OLMs are also useful for teachers who can get insight in the learning behaviour of individual learners or an overview of their class. Examples are concept graphs that display the domain knowledge to be learned or skill meters that summarise knowledge levels of top level concepts.

4.1.2 Technical Applications

Computer applications in the field of education that follow adaptation approaches are mainly Adaptive Educational Hypermedia (AEH) systems. They have their roots in Intelligent Tutoring Systems (see Section 3.1) and build on their core components (user model, domain model, tutoring strategy). In addition they introduce hypertext and hypermedia as content model and are typically Web-based.

ELM-ART (Weber & Brusilovsky, 2001) is an interactive, intelligent, and Web-based textbook that provides a course for learning the LISP programming language. The course is structured in both ways as hierarchy and as hypertext, as well as units containing text pages. The course is not just a static collection of linked pages, but it provides interactivity in two ways. First, the pages may contain exercises that the user has to solve. Second, the sequencing of the pages and exercises depends on the learning history that takes into account the results from the exercises and the previous visited texts. Adaptive navigation support is provided by sequencing exercises and pages, which is visually represented through coloured bullet points next to the links. Knowledge representation is realised through a domain model and user model. The domain model contains concepts that are related to text and exercises. The user model is an overlay model that relates user information to the domain model concepts. It is a multi-layer model that includes a visited state (visited text pages), a learned state (information regarding successfully solved exercises and related concepts), an inferred state (prerequisite concepts that are assumed to be known), and a known state (information what is already known).

A similar approach can be found in the AHA! system (De Bra et al., 2003; DeBra & Calvi, 1998). AHA! provides adaptivity through adaptive content presentation and adaptive guidance. Content pages (hyperdocuments) are organised as text pieces that individually are shown or hidden depending on user model information. Adaptive guidance is achieved through links that can be highlighted, hidden, disabled, or annotated. The user model is realised as an overlay model that refers to the concepts of the domain model. An open and modular architecture was one of the goals AHA!. The system has encapsulated the individual components (authoring tool, domain model, user model, adaptive engine) in system modules. In the context of the research project GRAPPLE, these concepts have been further developed (DeBra, Smits, Sluijs, Cristea, & Hendrix, 2010). First, a service-oriented architecture has been developed that includes the individual components are loosely coupled modules. Second, the adaptation approach has been defined through generic adaptation rules that are created with an authoring tool.

4.2 Self-regulated Learning and Meta-Cognition

This section gives an overview of self-regulated learning and its relation to technology-enhanced learning. This overview is presented from two perspectives. First, the theoretical and psychological background is described. Second, strategies and examples are listed, how learners can be support with technology to learn self-regulated.

The section includes text fragments from own contributions in peer-reviewed journal and book chapter publications (Nussbaumer, Dahn, et al., 2015; Nussbaumer et al., 2014).

4.2.1 Theory and Concepts

From a psycho-pedagogical point of view, *self-regulated learning* is a complex field of research that combines motivational as well as cognitive and personality theories. Components of SRL are cognition, meta-cognition, motivation, affects, and volition (Kitsantas, 2002). According to Zimmerman (2002) students can be described as self-regulated to the degree that they are meta-cognitively, motivationally, and behaviourally active participants in their own learning process. To define students' learning as self-regulated, they have to use specific strategies for attaining their goals and all this has to be based on self-efficacy perceptions. In this context there are mainly three elements important, namely the self-regulated learning strategies of students, their perceptions of self-efficacy regarding to their performance skills, and the commitment to their goals. The learners are active and able to control, monitor and regulate their cognition, motivational state, behaviour and context. Furthermore, the learners set goals and try to achieve them through progress-monitoring. These self-regulatory activities are mediators between personal characteristics, contextual features, and actual performance in the learning process. In a meta-analysis conducted by Hattie (2009) it turned out that performing self-regulatory activities in the learning process is one of the most effective methods to reach the learning goals.

Zimmerman has developed a *cyclic SRL model* (Zimmerman, 2002) consisting of three phases, which are the forethought phase (goal setting or planning), the performance phase (self-observation processes), and the self-reflection phase (self-reflection processes) (Figure 4.3). According to this model learning performance and behaviour consist of both cognitive and meta-cognitive activities. The cognitive activities are related to dealing with subject domains, for example acquiring domain knowledge through reading. The meta-cognitive activities are related to thinking about and regulating the cognitive activities, for example making a plan about domain knowledge acquisition.

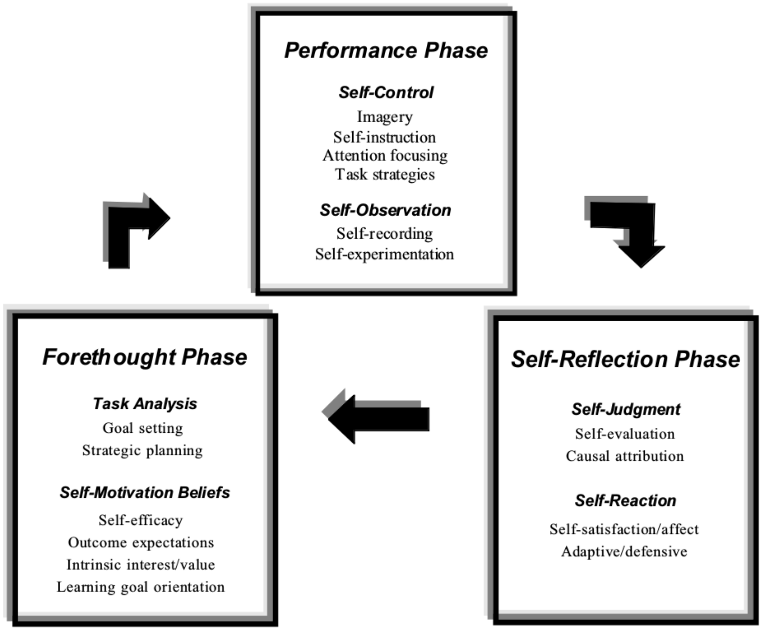


Figure 4.3: This picture shows the self-regulted learning cycle of Zimmermann (picture taken from Zimmerman (2002).

A similar approach is pursued by Boekaerts (1999) who developed the *layered SRL model* consisting of three layers (Figure 4.4). The first layer is about the regulation of the self, which is related to the choice of goals and resources. The second layer focuses on the regulation of the learning process, that relates to the use of meta-cognitive skills to direct the learning process. The third layer describes the regulation of the processing modes, which describes the choice of cognitive strategies. Also this model deals with cognitive and meta-cognitive activities, as well as with goals and resources.

A key role in SRL is given to *learning activities* that are also called learning strategies or learning processes. Dabbagh and Kitsantas (2004) listed six key-processes that are essential for SRL, namely goal setting, self-monitoring, self-evaluation, task strategies, help seeking, and time management.

- The *goal setting* process is defined as the outcome of a learning process and identifies strategies how to reach these goals. Goal setting motivates the learner's choice of and attention to the relevant tasks and it also motivates to attain higher effort and higher persistence over the course of time (Zimmerman, 2002). Furthermore, goal setting influences learning through affective reactions, for example higher self-satisfaction when goals are reached. Also the difficulty of a goal is an important factor for performance that increases with the difficulty

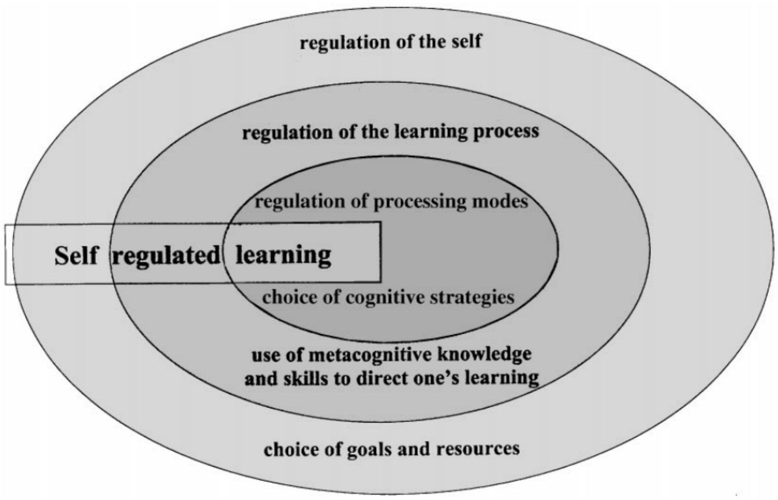


Figure 4.4: This picture shows the self-regulated learning model of Boekaerts (picture taken from Boekaerts (1999).

level of the goal (Locke & Latham, 2002).

- *Self-monitoring* is defined as one's reflected attention to an aspect of behaviour that directs the learners' attention to the task and assists them in evaluating the outcomes of their efforts. Self-monitoring is important because it helps learners attaining their goals by defining adequate learning adjustments.
- *Self-evaluation* is the process where the learner compares the learning outcome with the own goals. It fosters better skill acquisition, self-efficacy beliefs, intrinsic interest and self-satisfaction about performance.
- *Task strategies* is defined as the process of the learner who applies strategies which help reach the own goals. Studies indicate that students who applied strategies for learning had a better performance than students who did not apply them as much (Pintrich, 1990).
- *Help-seeking* is taking place if a learner identifies and calls upon outside resources. Thereby not only human help is meant, but also external analogue and digital resources.
- *Time management* is the process where learners manage the learning regarding time. Effective time budgeting highly correlates with academic achievement.

According to Roberts and Erdos (1993) *meta-cognition* is a key concept in the study of cognition and it plays an important role in the transfer of cognitive skills and in problem solving. Meta-cognition refers to knowledge and cognition about one's own cognition. According to Treier (2004) meta-cognition is a kind of self- monitoring, self-observation and self-regulation related to cognitive and information processing. Meta-cognition is the competence of reflecting a mental task critically and to organise involved learning and thinking processes in an efficient and effective way. The usage of meta-cognitive learning strategies is an essential component of self-regulated learning and is very important for flexibilisation and personalisation.

Supporting SRL in the right way is a crucial factor. On the one hand it means providing enough freedom for the learner, in order to stimulate motivation. However, on the other hand, too much freedom may be overwhelming and an appropriate guidance or even adaptation is usually needed to make the learning process effective and efficient. The concept of *guidance and freedom* is important, because it has been recognised that highly motivated learners attain a better learning performance if they have more control over their learning and are more autonomous (Issing, 2002). On the other hand some learners show difficulties in carrying out concrete meta-cognitive activities, such as planning, goal setting, monitoring, evaluating, and as a result often perform less successfully than would be anticipated (Bannert, 2006). Such learners are in need of guidance when learning. Furthermore, less motivated learners can also attain an improved learning performance if they receive more guidance. Keeping these reported findings in mind the individual support for learners should be tailored to suitable degrees of guidance and freedom. In this respect, the learner should be offered an optimal and balanced level of control and autonomy for their own learning process.

Motivation is a highly relevant aspect for achieving good learning outcomes and for performing self-regulated learning activities. Winne and Hadwin (2008) showed the positive impact of motivation on student's attention to their learning progress, on the progress itself and on the experience of satisfaction and positive affect. For the use of self- regulated learning activities a learner has to be motivated as these activities require additional time and effort. Ryan and Deci (2000) describe intrinsic motivation as one of the most important aspects regarding learning because it is the prototypical manifestation of the human tendency toward learning and creativity. Behaviours of intrinsically motivated learners are freely applied without the necessity of separable consequences. For intrinsic motivation to develop there is need for autonomy, competence and relatedness. However, there is also a need for extrinsic motivation and especially a good balance balance between extrinsic and intrinsic motivation (Covington, 2000).

Another important factor for SRL is *collaboration*. According to Dillenbourg (1999) collaborative learning comprises individually performed activities and also extra activities that are generated by interaction among peers. These collaborative activities trigger additional cognitive mechanisms, which may appear more frequently in collaborative learning situations than in individual learning. Students working in cooperative learning situations compared to individualistic or competitive learning situations have a higher performance at the mastery and retention of material, are more often using focusing, elaboration and meta-cognition strategies and develop ideas or solutions which are not gained if they work on their own (McConnell, 2000). Collaboration can also create both intrinsic and extrinsic motivation and is an essential strategy for stimulating curiosity, emulation, attention, persistence, opening new perspectives, increasing self-efficacy (Waite & Davis, 2006).

4.2.2 Technical Applications

Learners who are able to understand the SRL process and the related learning activities and who are able to perform them on their own can navigate freely through their learning processes. However, this requires the availability of a high degree of SRL capabilities (availability of the respective SRL competences). Since it cannot be assumed that all learners already have these abilities, guidance mechanisms are needed. Such guidance is often needed especially when learning with technology-enhanced environments (Bannert, 2006). Specific technology that aimed supporting SRL was developed in several research projects.

The iClass project aimed at developing an intelligent, cognitive-based open learning environment that supports the planning, monitoring, and reflection processes of a learner and at the same time personalise the learning process to the respective learner's preferences and needs (Aviram, Ronen, Somekh, Winer, & Sarid, 2008). In order to achieve personalised recommendations and reflection support, a competence model has been used that is basis for individual guidance (Steiner et al., 2009). This competence model is based on Competence-based Knowledge Space Theory (see Section 4.3) that structures competences through prerequisite relations. Visualisation tools have been created that display the competence structures and let the learner select learning goals and learning paths (Nussbaumer, Steiner, & Albert, 2008).

In the ROLE project a variety of methods have been developed and applied that support SRL in different phases (Nussbaumer, Dahn, et al., 2015). ROLE enables the learners to create their own learning environments by selecting and adding learning tools from an online repository. While some learners are able to make meaningful choices, others need support when they create and use their learning environment. For this purpose, a variety of different support strategies have been created. Teaser videos were created that explain the concept of SRL on a basic level for learners who are completely new to SRL. These videos introduce SRL to learners, makes the basic concept understandable, and in this way they try to motivate learners to learn in a self-regulated way. A course is another method to reach learners and provide them with assistance and knowledge about SRL and SRL tools in a compact way. The goals of such a course are to introduce the idea of SRL and enable the learners to use the ROLE technology in way that it supports SRL. Predefined learning environments address individual learning preferences with more or less support for SRL. The online repository provides support in terms of structured description of the learning tools. Each learning tool has metadata about its purpose, the intended SRL activity, the functionality it offers, and which content it addresses. A recommender uses this information and suggests learning tools fitting to the profile of a learner and the learning goals.

Another initiative that supports SRL is the Study Desk 2000 system (Narciss, Proske, & Koerndle, 2007). This system provides learning material and information on different topics and allow learners to explore and learn in a self-regulated way. In order to support learners to learn self-regulated, Study Desk 2000 offers three types of help. First, navigation and orientation support is provided by informing learners about their current location, their past activities and learning paths, and additional available learning material. Second, learning tools allow active participation in the learning process through interaction features, such as note taking, highlighting, access to a glossary. Third, monitoring and evaluation is provided through access access to the protocols of their learning activities. Thus learners can see what they have done, what they have achieved, and what is missing.

4.3 Competence-based Knowledge Space Theory

This section give a short introduction into Knowledge Space Theory, its competence-based extension, and applications in technology-enhanced learning.

The section includes text fragments from own contributions in peer-reviewed journal, conference, and book chapter publications (Albert et al., 2012; Nussbaumer, Gütl, & Albert, 2007; Steiner et al., 2009).

4.3.1 Theory and Concept

In the field of cognitive psychology there has been done much research to model knowledge domains of curricula and knowledge states of persons. Knowledge Space Theory (KST) is a mathematical-psychological theory which provides a set-theoretic framework for representing and assessing the knowledge of a learner (Albert, 1994; J. Doignon & Falmagne, 1999; J. Falmagne & Doignon, 2011). In KST a knowledge domain is identified with a set Q of problems. The subset of problems that a person is able to solve represents the knowledge state of this individual. Among the problems of a domain mutual dependencies will exist, such that not all potential knowledge states (i.e. subsets of problems) will actually occur. These dependencies are captured by a so-called prerequisite relation (also referred to as precedence relation), which restricts the number of possible knowledge states. Two problems a and b are in a prerequisite relation whenever the correct solution of problem a is a prerequisite for the mastery of problem b. Illustrated in a Hasse diagram (see Figure 1), ascending sequences of line segments indicate a prerequisite relationship. The collection of knowledge states corresponding to a prerequisite relation is called a knowledge structure. In a knowledge structure a range of different learning paths from the naive knowledge state to the expert knowledge state are possible (see Figure 4.5). Through defining individual starting and goal states of a learner, meaningful learning sequences with reasonable choices for navigation and appropriate levels of challenge can be realised for each learner.

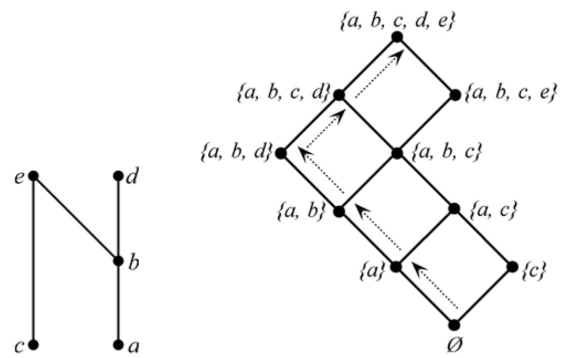


Figure 4.5: This picture shows prerequisite relations and the induced knowledge structure. Dashed arrows show a possible learning path. The picture is taken from Albert et al. (2012).

Competence-based Knowledge Space Theory (CbKST) incorporates psychological assumptions on underlying skills and competencies that are required for solving the problems under consideration (Heller, Steiner, Hockemeyer, & Albert, 2006; Korossy, 1997). This approach assigns to each problem a collection of skills which are needed to solve this problem and to learning objects those skills which they teach. Similar to the knowledge state a competence state can be defined than consists of a set of skills which the learner has available.

One of the origins of CbKST is the competence-performance-approach that was developed by Korossy (1997) as an extension to the original, rather behavioural KST. Korossy distinguishes between observable performances, i.e. test item solving behaviour, and their underlying competencies (in other approaches also denoted as skills). This is done by mapping each item to the subset of competencies required for solving this item and, vice versa, by mapping each subset of competencies to the subset of items which can be solved by a person who has all (and only) the competencies of the given subset. From these mappings, prerequisite structures on the sets of competencies and of performances (i.e. items) can be derived through the set inclusion principle: an item a is a prerequisite of item b (in the sense of the aforementioned surmise relation) if the set of competencies assigned to a is a subset of the set assigned to b. Figure 4.6 shows an example of three items A, B, and C to which subsets of competencies x, y, and z are assigned (denoted by the arrows). The set inclusion relation on the competence subsets (denoted by dashed lines) induces a surmise relation between the items (denoted by straight lines).

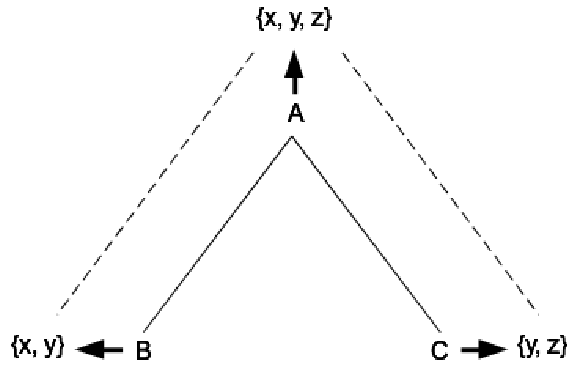


Figure 4.6: Competence assignment and induced prerequisite relationships (picture taken from Albert et al. (2012))

CbKST provides algorithms for efficient adaptive assessment to determine the learner's current knowledge and competence state, which builds the basis for personalisation purposes. Different approaches and algorithms are available, how competence assessment can be performed. One algorithm is based on a classical algorithm for probabilistic knowledge assessment that results in a knowledge state (set of assessment items that can be solved). (J.-P. Doignon, 1994). In a second step, the assessed knowledge state is then mapped onto the the competences assigned to the assessment of the knowledge state. Another way of doing competence assessment is the Simplified Updating Rule that allows to directly assess the competences by assigning and updating probability values of the competences. Each time the learner responds to an assessment item correctly or incorrectly, the related competences are increased or decreased. This includes both the competences related to the assessment item and also all other competences that are in a prerequisite relationship (Augustin et al., 2013).

Based on this learner information (knowledge and competence state), personalised learning paths can be created. The outer fringe includes those assessment items, that a learner is ready to learn next. Using the items of the competence sate, then the outer fringe consists of the items that have direct relations to items of the competence state. By consequently choosing items of the outer fringe, the learner can gradually and meaningfully move foreword.

The CbKST framework builds on a model which includes and connects learning objects, competences, and concepts (Heller et al., 2006). The mesh of these elements can be described by ontologies, which brings them into a standardised form. These relations offer several didactical possibilities, how to create learning paths and how to define learning objectives. The sequence of learning objects can be determined along the competences they teach. Goal setting can be done by defining competences to be achieved (competence goal) or problems to be capable of solving. The competence gap to be closed during learning is represented by the competences which are part of the goal but not part of the competence state of a learner.

4.3.2 Technical Applications

Several implementation approaches have been made, which outline diverse use cases of KST and CbKST.

The commercial ALEKS (Adaptive Learning with Knowledge Spaces) system is a fully automated, multi-lingual, adaptive tutor that grounds on KST (Canfield, 2001). The system provides individualised learning including explanations, practice, and feedback on learning progress for various disciplines, ranging from maths and natural science to social sciences. ALEKS adaptively and accurately assesses which concepts a learner already knows, what he/she is ready to learn next, which previously learned material should be addressed for review, and continuously updates a precise map of the learner's knowledge state (J.-C. Falmagne, Doignon, Cosyn, & Thiery, 2004).

The concept of CbKST were applied in the prototypical adaptive learning system APeLS (Conlan, Hockemeyer, Wade, and Albert, 2002). It can easily merge content from different sources to build an adaptive course. The only requirement is that the individual learning objects carry metadata information on required and taught competencies according to the competence learning structure approach given that the metadata author use the same competence terminology (Albert, Hockemeyer, Conlan, and Wade, 2001).

In the iClass project a semantic structure in Web Ontology Language (OWL) has been created to capture CbKST and concept map information and to relate their elements accordingly (Gorgun, Turker, Ozan, & Heller, 2005). In this way a curriculum can be expressed as a knowledge map, which in turn can be used for creating personalised learning paths and efficient assessment procedures. In order to create such knowledge maps, a software tool has been created which allows for defining the entities of the map and their relationship in a graphical manner (**?**).

4.4 Discussion

In this chapter three learning concepts (AEH, SRL, CbKST) are presented that have been employed in Technology-enhanced Learning (TEL) applications. Both differences and similarities can be observed in terms of their distinct models, pedagogical and psychological underpinnings, guidance, and impact on the educational sector. An overview is given in Table 4.1.

AEH has *distinct models* that clearly define the behaviour of the systems where implemented. Domain knowledge, user information, and adaptation strategies are precisely defined, which makes it possible to re-use them or to make them interoperable with other systems. Also CbKST has clearly defined models and algorithms that are mathematically elaborated and proven. SRL mostly don't has clear models in terms of technical formulation. They rather explain from a pedagogical and psychological point of view how learning should take place, in order to make it effective.

Theoretical underpinnings are strongly provided by SRL and CbKST from a pedagogical and psychological perspective. A lot of research was made that explains why SRL is useful and effective for learning. CbKST is based on a cognitive model that integrates psychological knowledge.

The theoretical basis of AEH is mostly driven by the technical development and not by pedagogical or psychological theories. However, they provide explanations in this directions. It has been shown that personalisation is useful for learning purposes in general, because they adapt to the personal characteristics and states of learners.

Guidance is provided by AEH and CbKST in distinct and clear manor. AEH has several methods with different levels of rigidity, in order to guide the learner through the learning material. Through scrutiny approaches some systems reveal the rationale of current adaptation. CbKST is even more rigid regarding guidance, as it often does not leave any alternatives or choices. SRL does either provide no guidance at all or provide smooth guidance through feedback, prompts, or recommendations.

Adaptability (self-personalisation) is typically not provided by CbKST and not or only a little by AEH (if they allow the user to change the adaptation strategy). SRL enabled systems give much freedom by nature and thus also allow adaptability.

All three learning concepts are research-driven and many prototypes, technical experiments, and user studies have resulted from the various research activities. However, only a few systems found their ways into *educational organisations*. The educational sector is still dominated by LMSs and incorporated systems following those approaches only to a very small extent and partly for research experiments.

Table 4.1: Overview of the learning concepts (AEH, SRL, and CbKST) regarding selected aspects.

	AEH	SRL	CbKST
Distinct models	+	o	+
Theoretical underpinning	0	+	+
Guidance	+	0	+
Adaptability	-	+	-
Impact on formal education	-	-	-

One of the main aims of this work is to develop an approach that combines these three to one integrated approach. So far, it seems that no efforts have been made to combine all three or at least two of them to a combined approach. However, it can be seen as an exception that AEH and CBKST have overlapping features, such as the use of the core models (user model, domain model, adaptation model). To some extent CbKST can be seen as a special case of an AEH approach. The next chapter (Section 5.2) presents the integrated approach that includes these three learning concepts.

Chapter 5

Framework for Competence-based Personalised Learning Support

This chapter presents a conceptual framework for competence-based learning support based on Adaptive Educational Hypermedia (AEH), Self-regulated Learning (SRL), and Competence-based Knowledge Space Theory (CbKST) learning concepts. In the last chapter (Chapter 4), these three learning concepts are explained on a theoretical level and with practical examples. By combining these learning concepts it provides a new learning approach that can be used for new Technology-enhanced Learning (TEL) solutions or integrated into existing Virtual Learning Environments (VLEs).

The goal of this chapter is defining this framework that integrates these three learning concepts, in order to benefit from the advantages of each of them. The integrated framework builds the conceptual basis for the technical framework and implementation presented in the next chapter (Chapter 6). The rationale of conceptual framework is to serve as a theoretical foundation for the development of the Compod service. Compod is a service with the aim to be used by any VLE. In this way the conceptual framework finds its way into existing VLEs and enriches them with its learning approach.

The first section of this chapter analyses the learning concepts regarding their individual features that are taken up by this framework. Then the conceptual design of the integrated framework is described in Section 5.2 by integrating individual features of AEH, SRL, and CbKST. Finally the framework is examined from the perspectives of different user groups in Section 5.3.

The framework has evolved over the years and different aspects of it have been published in peer-reviewed conference and journal publications (see also Section 1.4). The chapter uses text fragments from these publications and builds a new version of the framework (Albert, Nussbaumer, & Steiner, 2008; Nussbaumer, 2008; Nussbaumer, Gütl, & Albert, 2007; Nussbaumer, Gütl, & Hockemeyer, 2007; Nussbaumer, Hillemann, et al., 2015; Nussbaumer et al., 2008; Steiner et al., 2009).

5.1 Problem Statement and Requirements

As emphasised in Chapter 4, each of the three learning concepts AEH, SRL, and CbKST have characteristics that are beneficial for learning. Adaptation to the learner's knowledge and goals makes teaching and learning efficient, because it takes care for individual differences. Self-regulation in learning deepens the understanding and increases motivation. Focusing on competences and their development increases the knowledge and understanding of learners. Hence, there are good reasons for the use in TEL applications of this research and respective results.

However, they also have shortcomings and drawbacks. For example, AEH and CbKST tend to be restrict the learning processes and learning paths by reducing the choices and freedom of the learners. CbKST does not have concepts to explain the adaptation strategy to the learner, but keeps this information secret. SRL provides little information how it can be employed by TEL applications.

The goal of this work is to provide a new learning approach that originates from the combination of AEH, SRL, and CbKST. Despite their individual characteristics, strengths, and weaknesses, they are not mutually exclusive. Especially the fact that they originate from different research fields provides opportunities to combine them to an integrated framework. The remainder of this section outlines the individual characteristics that are taken into account.

Research on AEH is mostly based in computer science with influences from pedagogy and psychology. This is expressed in models and concepts that are close to technical development and in an approach that has great focus on the role of the computer applications. The following characteristics are used for the integrated framework:

- Subject domains, learner knowledge, and adaptation techniques are represented in distinct models that can be directly used for implementation.
- Adaptive systems are capable of guiding the learner through the subject domain and available content (in a more or less rigid way).
- Partly, The concept of Open Learner Model (OLM) is integrated in adaptive systems, which opens up domain and learner model information to the leaner.

Research on SRL originates in pedagogy and psychology. The role of computers is rather seen as a tool for learning and is not so much centre of research. The main characteristics to be incorporated into the conceptual framework are:

- There are models of cognitive and meta-cognitive learning activities and explanations how these activities take place during the learning process.
- SRL knows the concept of guidance and freedom stating that the learner should control the own learning process, but gets guidance if needed.
- On a theoretical level SRL is closely connected to intrinsic motivation. By learning self-regulated (with guidance if needed), the learners become or stay intrinsically motivated.

CbKST is grounded in cognitive psychology in a stream that uses mathematical models for formulating theories. Empirical and formal research is conducted on its algorithms and knowledge representation models, which makes the theory solid. Characteristics that are taken from CbKST are:

- Subject domains and learner information are represented through a model that is based on a mathematical-psychological theory.
- Mathematical algorithms for learning path creation and assessment are available, which makes learning efficient.
- The term competence is clearly defined and inherently part of the knowledge representation and algorithms for learning paths and assessment.

The integration of AEH, SRL, and CbKST leads to several new characteristics that can be considered as high-level requirements. The essential characteristics to be taken into account include (a) a knowledge representation model that builds on CbKST, (b) meta-cognitive and SRL activities that are performed with respective functions or tools of a learning system, and (c) personalised support through recommendation and feedback techniques, and (d) assessment and user tracking that feed into the learner model. Thus the high level requirements are formulated in Table 5.1.

Table 5.1: High-level requirements for the conceptual framework.

REQ 1	A domain model is used that employs CbKST knowledge representation of structuring competences, learning objects, and assessment items.
REQ 2	The learner model is destined as an overlay model that refers to the competences, learning objects, and assessment items of the domain model.
REQ 3	Algorithms for creating learning paths and assessment are used from CbKST. These algorithms are adaptive as they are based on the current competences state stored in the user model.
REQ 4	The algorithms for learning path creation and assessment are not necessarily applied as strict adaptation, but rather appear as monitoring, recommendation, or feedback.
REQ 5	Meta-cognitive and SRL learning activities are supported through distinct functions or tools.
REQ 6	The activities of the leaner are tracked, stored in the user models and used for feedback and recommendation.
REQ 7	The learner should get access to the information of the domain and user model.
REQ 8	A teacher or tutor gets access to the user models of individual or groups of learners.

It is important to note that it depends on the VLE which of these requirements are taken up and how they are integrated. The overall goal of the conceptual framework is to serve as a foundation for different types of VLEs, which leads to different ways of shaping the individual requirements. Chapter 7 presents several ways how they are taken up by different VLEs.

5.2 Framework Design

This section uses text fragments and diagrams from journal and conference publications and builds a new version of the conceptual framework (Albert et al., 2008; Nussbaumer, 2008; Nussbaumer, Gütl, & Albert, 2007; Nussbaumer, Gütl, & Hockemeyer, 2007; Nussbaumer, Hillemann, et al., 2015; Nussbaumer et al., 2008; Steiner et al., 2009).

The overall design of the conceptual framework for competence-based personal learning support is depicted in Figure 5.1. It connects characteristics of AEH, SRL, and CbKST as described in the last section and creates a new learning approach out of them. The framework consists of three layers, which are (1) the *knowledge representation model* for domain and learner information, (2) *personalisation methods* consisting of personalised learning support techniques (monitoring, assessment, recommendation, and feedback), and (3) a *self-regulated learning process model* that includes meta-cognitive and SRL learning activities performed in connection with respective tools.

The framework has a hybrid nature, as it connects information models, personalisation techniques, and meta-cognitive activities. In this way it constitutes a new learning approach for TEL solutions that addresses learning from the cognitive perspective, knowledge representation, and personalisation techniques. Thus it serves as a basis for the integration of learning and technology. This section elaborates each layer in detail.

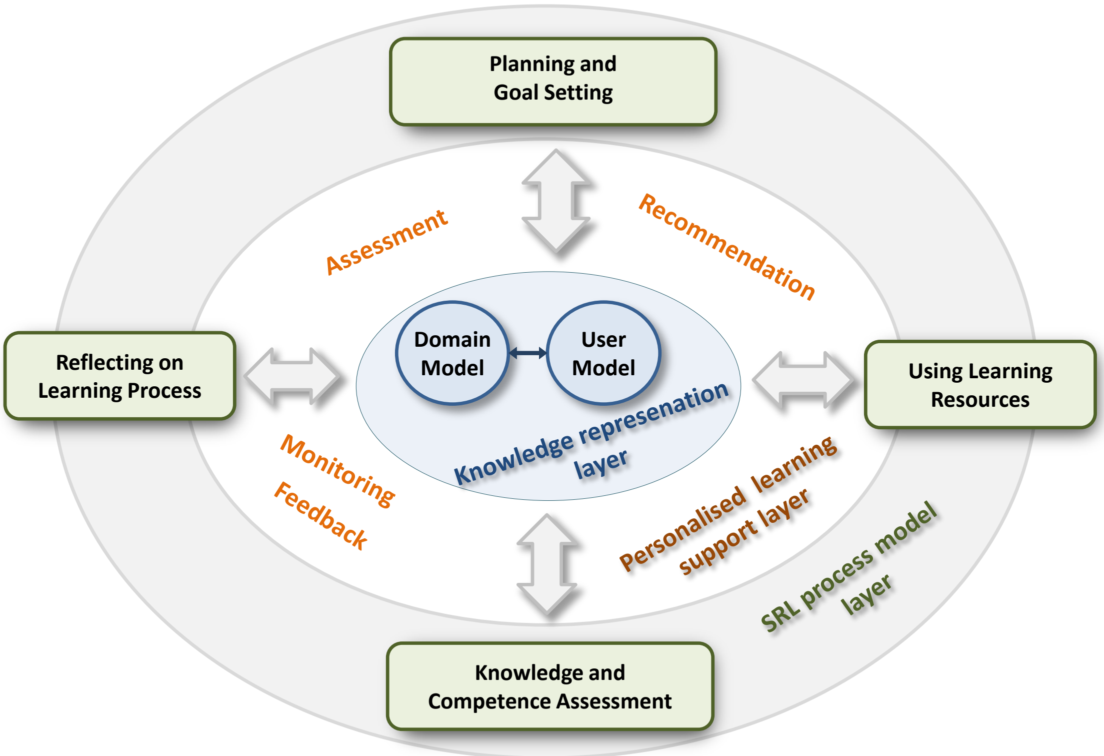


Figure 5.1: This figure depicts the conceptual framework for learning support consisting of three layers. The knowledge representation model is in the centre, the personalisation methods are in the middle layer, and the SRL process model are in the outer layer. The image is taken and modified from Nussbaumer, Hillemann, et al. (2015).

Knowledge representation model

The central piece of the framework is the domain model that formally covers the subject domain to be learned. CbKST provides a methodology to structure a subject domain and also makes it usable for a technical application. The core elements as used in this framework are learning objects, assessment items, and competences. Competences are structured through prerequisite relations, meaning that it can be assumed that, if competence A is a prerequisite of competence B, then a learner having competence B also has available competence A. Figure 5.2 depicts an example of a prerequisite structure of five competences (A, B, C, D, E) in an acyclic directed graph. Competences below others are prerequisite for them, if connected through a path to them. This type of graph is also called Hasse diagram.

In order to structure a subject domain, the first step is to define competences necessary to master it. These competences are then structured according to their prerequisite relations into a competence map. In addition to competences, learning objects are created that convey these competences and assessment items are defined that test these competences. Thus, relations between learning objects, assessment items, and competences are established. The set of all elements and their relations is called the domain model (see Figure 5.2). Such a domain model is usually created by a domain expert or teacher.

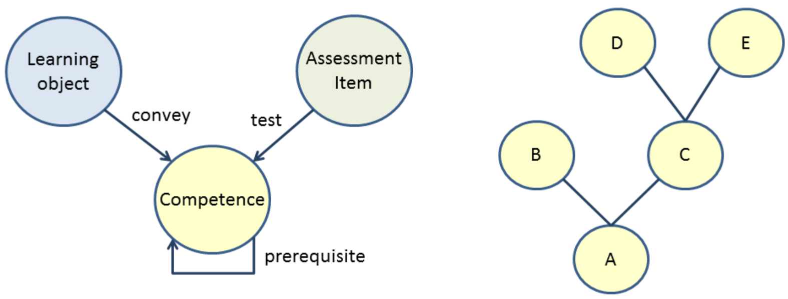


Figure 5.2: The diagram depicts the domain model structure on the left site and an example of five competences with prerequisite relations between them on the right side. The image is taken from Nussbaumer, Hillemann, et al. (2015)

The user model is another core component of the framework. In general, the user model follows an overlay design (Brusilovsky & Millán, 2007) meaning that the user model elements are related to and defined by other models. In our case, the user model refers to the domain model and the tool interaction model (see below). The user model allows for defining information about the learner's knowledge, competences, goals, learning history, and used tools. It relates to both aspects of the domain model and aspects of the self-regulated learning, and thus connects them. Table 5.2 gives an overview of the information contained in the user model.

Table 5.2: Overview of the user model and the contained information

Category	Information	Description
Learning State	Knowledge State	The assessment items that a learner can solve
	Competence State	The competences a learner has available; each time a learner solves (or fails to solve) an assessment item, the related competences are added to or removed from the competence state
	Competence Goal	The competences that a learner wants to acquire
	Competence Gap	The competences needed to achieve the competence goal
Learning History	Learning Objects	The learning objects a learner has visited
	Assessment Items	Answers to assessment items including the information if solved or failed
	Learning Tool	The tools and their submenus that a learner has used
	Help	The help information that a learner has requested (related to a tool)

Self-regulated learning process model

The outer layer describes the SRL learning process with related meta-cognitive learning activities. The learning process is a rather generic term that refers to all cognitive and metacognitive activities of the learner, as well as the interactions with the learning system. The learning process starts when the learner begins to learn and ends when the learner has finished learning (independent of the results). In order to operationalise the learning process, a self-regulated learning process model is defined that connects self-regulated learning concepts with elements of the domain model (topics to be learned). The learning cycle is related to the iterations within this process. A system that features these phases by offering appropriate tools can be regarded as an environment that enables self-regulated learning.

This model follows the ideas of the cyclic SRL model of Zimmerman (2002) and SRL activities defined by Dabbagh and Kitsantas (2004). It describes learning as a cyclic sequence of four main phases: 1) planning and goal setting, 2) using learning resources, 3) knowledge and competence assessment, and 4) reflecting on learning behaviour and progress. For each of these phases, a visual tool that supports the respective cognitive and metacognitive activities is provided. In the planning and goal-setting phase learners set their short-term goals, in order to plan what they want to learn next. This phase is mainly related to the metacognitive activity of planning. In the next phase, the learners make use of learning resources fitting to the selected goals, in order to attain related domain knowledge. Learning in this phase mainly happens on the cognitive level, but is also related to the metacognitive level of self-observation. Then the learners undergo a knowledge assessment regarding the recently used learning content and current learning goal. This phase is also on a cognitive level and related to the self-monitoring activity. Finally, learners should reflect on the activities and outcomes of the last phases. The current goal, the visited learning objects, and the assessment results are visually displayed. Reflecting on learning behaviour and progress targets the metacognitive activities of self-reflection and self-evaluation. A learning cycle is defined as iteration through these four phases. An overview of these phases and their relations to cognitive and metacognitive activities is shown in Table 5.3.

Table 5.3: Overview of the cognitive and metacognitive learning activities in the SRL process model

SRL phase and related tool	Metacognitive activity	Cognitive activity
Planning and goal setting	Planning	Understanding the subject domain
Using learning resources	Self-monitoring	Attaining domain knowledge
Knowledge and competence assessment	Self-monitoring	Knowledge assessment
Reflecting on learning behaviour and progress	Self-reflection, self-evaluation	Knowing the learning progress

Personalised support methods

Traditional adaptive systems use domain and user models to create learning paths automatically consisting of learning object and assessment item sequences. Though such approaches are personalised, the learners just follow the paths without having alternative options. The other extreme would be an approach where all learning objects and assessment items are available and the learner is free to choose, but without any help, recommendations, or feedback from such a system. While the first type of approach might be efficient for weak learners by offering strict guidance, it does not provide the advantages of self-regulated learning. On the other hand, also the second approach has its weakness, because it does not provide any support. The goal of this framework is to establish an approach that offers freedom and support at the same time.

Learning Analytics methods are employed by exploiting the user model data and presenting relevant information in a graphical way. This representation should stimulate the learner's reflection and motivation. Instead of operating with pure log data, high-level information (based on competences, learning objects, and assessment items) is presented to the learner. Since the user model holds the history data in time sequences, calculations must be performed to extract information as described above (reflection phase). An Open Learning Model approach is employed by displaying information in a graphical way that allows the learner to self-regulate his own path through the learning resources. Personalisation is implemented by giving visual recommendations in terms of selecting next goals and choosing next learning objects and by offering assessment items depending on the previous learning behaviour.

A major goal of this framework is to provide personalised scaffolds that assist learners in a self-regulated manner. These scaffolds are based on the domain model and the user model. Since the user model contains information on the individual learning history, the support can be adapted to the individual learner and thus be personalised. Personalised scaffolds are given to the learner in each SRL phase differently depending on the phase and related tool. In order to provide personalised support, four types of methods are available:

- ***Competence assessment.*** The goal of competence assessment is to determine the competences that a learner has available. Competence assessment relies on the assessment procedures of CbKST (see Section 4.3). In principle, assessment is performed by posing assessment items to the learner who has to respond on them. The items are defined in the domain model and are associated with competences. The selection of the assessment item depends on the currently available competences (competence state). If a learner responds on an item with a correct or incorrect answer, then the competence state is updated accordingly. For performing the assessment two algorithms are used. First, the classical algorithm for assessing the knowledge state of a learner with a probabilistic model of possible knowledge states (J.-P. Doignon, 1994). The assessed knowledge state is then mapped onto the competences. Second, the Simplified Updating Rule allows to directly assess the competences by assigning and updating probability values of the competences. Each time the learner responds to an assessment item correctly or incorrectly, the related competences are increased or decreased. This includes both the competences related to the assessment item and also all other competences that are in a prerequisite relationship (Augustin et al., 2013).
- ***Monitoring.*** The monitoring technique is a non-invasive way of tracking what a learner is doing by logging all actions on the content and tool level. Actions on content level include the visited learning objects and the correct or incorrect answers to assessment items. Furthermore, also the changes of the competence state is tracked. Actions on tool level include the used tools and their functionalities. Since the use of tools is associated with meta-cognitive SRL activities, this is also a tracking on the SRL level. All this information is stored in the user model (see Table 5.2).

- ***Recommendation.*** Recommendation is provided on the content and tool level. On the content level, learning objects are recommended that fit to the current competence state. Learning objects related to competences that are part of the outer fringe (see Section 4.3) are recommended as those to be learned next. Recommendation on the tool level is provided by recommending tools to be used. As tools are related to SRL activities, this type of recommendation can be regarded as SRL guidance.
- ***Feedback.*** Feedback is provided by presenting aspects of the user model to the learner. Such aspects are for example the currently available competences (competence state), the current learning goal (goal competences), the visited learning objects or relate competences, and the used tool. These aspects can be presented individually or in combination. The presentation is typically done in a visual and graphical way. For example, the competence state can be presented with highlighted competences on the competence graph.

The conceptual framework does not strictly define how the support techniques are used in the respective SRL phase. Instead, it depends on the VLE how they deal with the information provided respective technique. Examples how learning support techniques are applied in the respective phase are:

- ***Planning and goal setting.*** The learner gets a visual representation of the competences, including visual clues of the current competence state, so that the goal-setting activity is guided by the prerequisite structure of the competences and the current competence state.
- ***Using learning resources.*** The learner gets recommendation for learning objects that are meet the current competence goal. Furthermore, visited learning objects are visually marked.
- ***Knowledge and competence assessment.*** Assessment items are presented to the learner that fits to the current competence state (the assessment items with a fitting difficulty level).
- ***Reflecting on learning behaviour and progress.*** The learning history in terms of visited learning objects and completed assessment items, acquired competences, and used learning tools are graphically depicted.

5.3 User Perspectives

This section describes the stakeholder roles addressed by the conceptual framework. The learning approach included in the framework design is clearly learner-centred. The learner is put into the centre of the learning process, the technical environment, and the educational context. The learner should take over control of the own learning process when using a VLE that facilitates the learning approach of this framework. Teachers or tutors may organise learning sessions including the selection of subject domains formally structured as domain models. The domain models are typically created and maintained by external content authors, but also by teachers or tutors. Finally, the provision and maintenance of the technology is performed by the technical administrators that are often part of educational organisations.

Learner

Competence-based learning and self-regulated learning are the main pedagogical and psychological learning approaches applied in this work. In detail, the learner is addressed in the following ways:

- The primary goal of the learner is to acquire the knowledge and competences of a subject domain.
- Additionally, the learner should be empowered to learn in a self-regulated way.
- Learners get access to the knowledge resources (learning material, learning objects).
- Learner get access to the tools that support meta-cognitive and SRL activities.
- Personalised support is provided to the learner for accessing knowledge resources should be provided.
- Personalised support is provided to the learner for learning in a self-regulated way should be provided.
- Learners can create domain models as a learning activity that increases their understanding of the subject domain

Teacher and tutor

The role of teachers and tutors are also supported in this approach. However, because of the focus on self-regulated learning, teacher and tutors are not necessarily required. In detail they are addressed in the following way:

- Teachers and tutors are empowered to create, modify, and manage subject domains in terms of domain models
- Teachers and tutors can easily organise lessons by assigning learners to subject domains
- Teachers and tutors can organise lessons as blended learning approach by integrating online sessions in their classroom lessons
- Teachers and tutors can monitor the learning behaviour and progress of individual learners and group of learners

Administration

In order to practically use the learning approach, it has to be technically implemented and deployed. The deployment and maintenance of the technology requires people and organisational structures. This work is done by administrators who are addressed in the following way:

- Administrators take care for the deployment of technology that facilitates this learning approach.
- Maintenance in terms accounts and user data is done by administrator (or teachers/tutors).

5.4 Discussion

This chapter presents the conceptual framework for competence-based personalised learning support. This framework constitutes and defines the learning approach of this work. It consists of three layers, the knowledge representation model, the personalisation strategy, and the self-regulated learning process model. The rationale of this framework is to provide a theoretical basis for the development of the Compod system and the VLEs that integrate this system (see Chapter 6). The framework itself is grounded on research in the field of AEH, SRL, and CbKST (see Chapter 4). In this way the framework serves as the connection between research in TEL and system development of this work.

The overall approach of this work consists of a conceptual and technical framework and an external VLE that takes up and integrates their key features. Referring to the psychological learning theories described in Section 2.2, behaviourism, cognitivism, and constructivism are addressed in different ways. The behaviourist theory is more or less directly addressed by the functionalities of the core service. The constructivist theory is partly addressed by the core service, but also addressed through an external VLE. The constructivist theory is mostly addressed by an external VLE, but significantly supported through the conceptual framework and core service. In detail, the learning theories are addressed by incorporating several recommendations of them provided for the design of a VLE:

- ***Behaviourism.*** The framework complies with many guidelines of the behaviourist theory. For example, learning material is broken down into small steps, learning activities are sequenced for increasing difficulty, task are adapted to the learner's knowledge state, activities are responded with feedback, and assessments are provided.
- ***Cognitivism.*** Guidelines from constructivist theories are incorporated partially, but are also supported indirectly. A well structured content is provided through the domain model, however, layout, multi-modality, and multi-sensory features of the delivered content is task of the VLE that makes use of the framework. Explanations what and why something is learned partly relates to the planning phase of SRL, but is also left to the VLE. A focus on competences is clearly part of the framework, especially with respect of CbKST. SRL with their meta-cognitive learning activities are cognitivist constructs.
- ***Constructivism.*** The constructivist theory is mostly addressed indirectly. For example realistic environments and problem-based learning is not directly featured by the framework, but facilitated by the VLE. However, learning material, tasks, assessment items of these VLEs are structured according to the knowledge representation model and personalised support can be provided for such VLEs. Ownership of learning is provided through the support for SRL. Multiple information sources can be addressed, as content can be made up from references to external learning material. Creation of knowledge as a major aspect of constructivism is achieved by the of domain models by learners. Even if these domain models are not used for personalisation, the creation is a learning activity that deepens the understanding of the subject domain. Collaborative learning is not addressed in this approach.

The learning approach is clearly learner-centred, as it empowers learners to take over control of their own learning process. Teachers, tutors, and administrators play a role in this approach, but rather initiate, facilitate, and monitor the learning processes. The goal is to integrate this approach in existing VLEs, which changes their way of learning of the respective VLE:

- ***AEH.*** This type of VLE benefits from the CbKST approach of structuring subject domains, recommending learning material, and assessment of competences. Furthermore, feedback and visualisation of leaner model information can be integrated.
- ***LMS.*** This VLE type can benefit from the knowledge representation model which is typically missing in LMSs. In addition, SRL functionalities can be included and supported.
- ***PLE.*** PLEs give freedom to the learner, but do not provide support structured for the learning process. Hence, they can benefit from the personalised support strategies in terms of knowledge acquisition and

- ***VRLE.*** Similar to PLEs, they give freedom to the learner as they typically can free navigate through the virtual space. So they can make use the personalised support for knowledge acquisition and self-regulated learning.

The next chapter presents the technical realisation of the core system that implements the conceptual framework. This implementation takes up the requirements and designs of the conceptual framework and makes them available for external VLEs. The connection of the theoretical basis, the conceptual framework, the core service, and the integration with an VLE constitutes the main approach of this work. The role of the conceptual framework is the formalisation of the theoretical basis for the development.

Chapter 6

Compod System

Details of the technical framework and related implementation are described in this chapter. Following the conceptual framework presented in the last chapter, the implementation of the conceptual framework is described in here. The implementation resulted in the *Compod system*, which consists of Web service, an authoring tool, a course tool, and a reference implementation of a VLE. The name *Compod* is an acronym of *Competence Pod* meaning that it is a software component dealing with competences. The technical design of these components is the technical framework.

This chapter aims at describing the individual components. The Web service (Compod service) as the core component that implements the learning approach of the conceptual framework is described in Section 6.1. Then the interfaces and related data models are presented in Section 6.2. After that, Section 6.3 presents the the Compod VLE, which is a reference implementation of an VLE that demonstrates the use of the Compod service. Finally, the authoring tool (Section 6.4) and the course tool (Section 6.5) are described. The authoring tool allows for creating and managing domain models and the course tool is used for managing courses and monitoring individual learners and groups of learners. The . All together, these components form the Compod system.

The chapter includes text fragments from own contributions in a peer-reviewed journal publication (Nussbaumer, Hillemann, et al., 2015).

6.1 Design of the Compod Service

The section includes text fragments from own contributions in a peer-reviewed journal publication (Nussbaumer, Hillemann, et al., 2015).

The Compod service is the core part that implements the learning approach of the conceptual framework described in last chapter (Section 5.2). Furthermore, it is designed to exposed the functionality of facilitating the learning approach to external VLEs. For this reason, it is implemented as Web-based service with a REST interface for exposing its functionalities. Through this interface it provides access to the user and domain model, as well as to the personalised learning support components (assessment, monitoring, recommendation, and feedback). The service is developed as a Java servlet and can be deployed on any Web application with a servlet container (e.g. Apache Tomcat). The overall technical design is outlined in Figure 6.1. This diagram outlines the main components of the service.

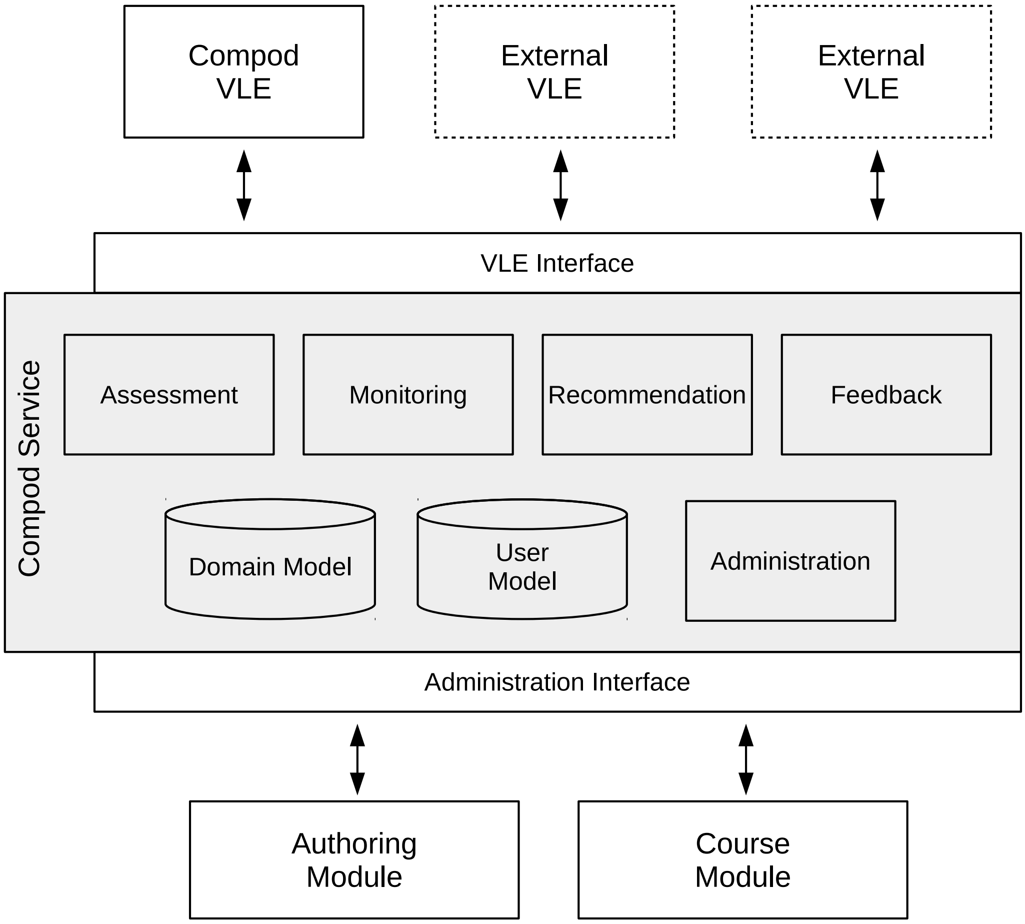


Figure 6.1: This image displays the overall architecture of the Compod service.

The domain model component is responsible for storing and managing domain models. Domain models are represented in XML format and contain information regarding learning objects, assessment items, and competences, as well as the relations between these elements. Domain models can be added, removed, or edited - as a whole or individual parts of it. The REST interface exposes methods to store and retrieve whole domain models, but also offers reasoning on it, which allows to retrieve individual elements of it. For example, learning objects related to a specific competences can be searched for and retrieved. Domain models are stored in a MySQL data, where whole XML structures are stored in indiviudal database rows.

The user model component manages and stores user model data as outlined in Section 5.2. There are two parts, which are the learning state and the learning behaviour. External VLEs can either store User model data directly in the user model (e.g. set a new competence goals) or user model data is retrieved from the monitoring component (e.g. when an external VLE tracks a learning activity). Retrieving user model data is done in two diff rent ways. Data of the learning state can be retrieved as they are and data of the learning history are retrieved in aggregated form (see below). For all these functionalities REST interface methods are available.

The monitoring component captures the interaction data from external VLEs and stores it in the user model as an extended semantic triple. While the semantic triple has the form <subject, predicate, object>, the extension adds contextual information about creation time and domain model. The subject is related to the learner who induced the information. The predicate describes the type of information; for example, learning object visited, assessment item solved, assessment item failed, current competence goal, or current competence state. The object contains the actual information according to the predicate type, which can be, for example, a learning object, an assessment item, or a competence. The domain model information is needed to specify the subject domain to which the triplet is related. For example, a student can learn two different subject domains at the same time, which has to be made distinguishable. This way of structuring user model information creates a flat structure that can be browsed and analysed easily.

The assessment component manages the knowledge and competence assessment. It selects and recommends assessment items based on the current competence state and competence goal. Based on the answer to the assessment items, it updates the competence state. This procedure can be done in two different ways, using the modified knowledge assessment proceudre of the Simplified Updating Rule (see Section 4.3). It depends on the external VLE and context, which one is used. The communcation with the external VLE is provided over a REST interface method where informatin is exchanged in XML format.

The recommendation component selects learning objects fitting the current competence goal and competence state. It also takes into account previously visited learning objects. These components form the basis for the personalisation approach and personalised guidance. The algorithm for selecting recommended learning objects follows the concept of outer fringes (see Section 4.3). The communcation with the external VLE is provided over a REST interface method where informatin is exchanged in XML format.

The feedback component is responsible for analysing the user model information and creating meaningful reports that help learners gain insight into their learning process and improve their learning. For example, it contains statistics on the visited learning objects and completed assessment items in relation to the competence goals. Furthermore, it includes information about how the competence state evolved over time throughout the learning process. This information is provided in XML format via the REST interface and is the basis for the visualisations in the user interface.

The administration component is responsible for managing user accounts and for dealing with software configuration. User accounts consist mainly of anonymous unique identifiers needed for the assignment of user information to unique users. Additionally, they can contain full names, email address, and other information, if needed by external VLEs. Software settings mainly refer to settings about the database and file storage at the system where Compod is installed.

The VLE interface is the REST interface for the external VLEs. Through this interface they can access the personalised learning support components. The administration interface is the REST interface for the authoring and course modules. They can access the domain and user model data, as well as the course module.

6.2 Interfaces and Data Models

Following the elaboration in Section 5.2, **key constructs** can be identified that form the basis for the information models of the implementation and its interfaces. These constructs are used to structure the learning domain (domain model), to store user information (user model), to provide personalised learning support, and to monitor learning activities. These constructs are listed and described in Table 6.1.

Table 6.1: Key constructs of the Compod service.

Competence	According to CbKST, competences are constructs that are needed for solving problems and that explain why problems can be solved. Thus, it is a main learning goal to attain competences. In CbKST competences are defined and used to structure learning domains. The definition of competences including their granularity level is the content author's responsibility.
Learning object	Learning objects are small units that should teach and convey competences. In our case they Web resources represented by URIs. Thus learning objects can be any resources including Web pages and build-in resources in a VLE. Learning objects are assigned with competences indicating that they teach that assigned competences.
assessment item	Assessment items are problems posed to the learner, in order to test the availability of the assigned competences. They can be multiple choice questions as part of the domain model or URIs that represent any resource on the Web or of an VLE.
Learning tool	Learning tools are software components that are used to acquire or test knowledge and competences.
SRL activity	SRL activities are meta-cognitive activities related to self-regulated learning, including goal setting, self-monitoring, self-assessment, and self-reflection.

In order to define and represent the knowledge of a subject domain, **domain models** are defined. They contain information of the competences included in the subject domain, the learning objects to be used for learning tasks, and the assessment items to test the competences. Competences are structured through prerequisite relations, and are assigned to learning objects and assessment items. This structure follows the knowledge representation model described in Section 5.2.

Domain models are represented in XML format, which contains all information regarding competences, learning objects, and assessment items including their relations to each other. There are different sections in the XML format dedicated to the list of competences, learning objects, and assessment items, as well as sections containing the structural information. Each construct has a unique identifier within the domain model, which allows to reference them. Originally, the domain model was expressed in OWL format, which, however, turned out to be to complicated for VLEs that do not have OWL parses. Thus a simplified XML format has been chosen as domain model format.

The **user model** is represented through two information models, which are the learning process model and the history model. The the contained information including this separation is explained in Section 5.2. An important characteristics of these models are the unique reference to a domain model, which forms a context for the user information. This is needed, because competences, learning objects, and assessment items are related to each other within a domain model. thus also the references to these constructs must be kept in the user model.

The **learning process model** contains information on the learning goal, which is defined as a set of competences. Furthermore, it contains information on the probability values of the competences. This concept follows the Simplified Updating Rule (Augustin et al., 2013) where each assessment results in a change of probabilities if competences are available. It also contains the information which and how often assessment items and learning objects have been visited. Using this information, visited competences can be derived from that. Similar to the domain model, this information is represented through a simplified XML format.

The **learning history model** contains information of the activities that learners have been performed. Each time a leaner visits a learning object, completes an assessment item, uses a learning tool, or gets a recommendation, the respective information is stored in the learning history model. This information is stored following the semantic triple approach of representation information in a "subject - predicate - object" format. This format allows to store which learner performed which type of activity with which content, where content is for example the concrete learning object or assessment item. In addition to the semantic triple, context information is provided. This includes, the used VLE and domain model. The learning history is stored in tabular form.

While the learning history model is related to the behaviour of the leaner, the learning process model is related to the cognitive state of the leaner. Learning history information include observable actions and can stored directly in the model. Cognitive states are either calculated from behavioural actions (e.g. with a competence assessment algorithm) or directly provided by the leaner (e.g. through goal setting).

In order to make available these models for the external VLEs, **interfaces** are needed to store and retrieve respective information. In principle, there are two types of interfaces. First, there interfaces that allow to directly store and retrieve information. For example, current learning goals are selected by the learner though a goal setting tool that directly stores this information in the user model. Second, there interfaces with components behind that manipulate information. For example, when performing an assessment and sending the completion to the Compod service, the assessment component calculates competence probability values out of this information and stores them in the user model.

As outlined in Section 5.2, there are four components for personalising the learning support. These components are accessible though several interfaces of the Web service. Table 6.2 gives an overview of these components in terms of the key constructs and data models they use for their individual learning support techniques.

6.3 Compod VLE

This section describes the Compod VLE that functions as a reference implementation of a VLE connected to the Compod services. It provides a user interface for learners that features and demonstrates many learning support techniques of the Compod service. Furthermore, it demonstrates the a technical implementation how to use the Compod service. Compod VLE also has been used for the evaluation of the overall learning approach (see Chapter 8).

The section includes two parts. First, the individual tools are described with their meaning for self-regulation and competence-based learning. Second, a scenario is presented that describes how these tools can be used for effective learning.

The section includes text fragments from own contributions in a peer-reviewed journal publi-

Table 6.2: Components for personalised learning support.

Assessment	The assessment component performs that competence assessment. It uses the (correct or incorrect) answers of learners to assessment items and updates the probability values out of them. It can also recommend next assessment items to be solved. However, this decision can also be left to the learner following the SRL approach.
Monitoring	The monitoring component more or less just takes the activities of the leaner and stores them in the learning history.
Recommendation	The recommendation component suggests learning objects to visit next and learning tools to use next. It provides multiple items which allows the leaner to chose. This learning object recommendation takes into account which learning objects have been used and which competences have been visited. The tool recommendation is based on the previously used tools in combination with the SRL activities performed with them.
Feedback	The feedback component provides user model information including both the learning process model and the learning history model. While information from the learning process model is directly included, the information from the learning history is aggregated (e.g. the number of correctly answered assessment items).

cation (Nussbaumer, Hillemann, et al., 2015).

Tools

This user interface consists of four tools representing the four phases of the SRL process model. Each tool supports the cognitive and metacognitive activities of the respective phase. Switching between these tools can be done by clicking on the tool name on top of the user interface. The tool names are the catchwords Plan, Learn, Assess, and Reflect. Following the sequence of the phases is suggested but not mandatory.

The first tool addresses the goal-setting activity (see Figure 6.2). This tool displays the competence map consisting of the competences of a domain model and the prerequisite relations between these competences. As overlay information, it also depicts the current competence state by drawing the contained competences as bigger green circles. Furthermore, it displays the current competence goal by drawing a red border around the circles. The user can add or remove competences by clicking on the respective ones. The prerequisite structure serves as guidance to navigate through the subject domain. The learner is free to choose any competences, but from a pedagogical point of view, it is meaningful to start with competences that have no other competence as prerequisite and then move up along the prerequisite relations. Thus, the prerequisite structure and the current competence state are scaffolds for the learner to choose goals and navigate through the subject domain.

The second tool is used to browse through the learning objects (Figure 6.3). All learning objects are listed on the left side, while the recommended learning objects are painted with a red border. Visited learning objects are marked with a blue line on the right side. Learners are free to choose, but it is recommended by visual scaffolds to follow the learning objects associated with the competence goal chosen by the learner.

The assessment tool, the third tool, provides two options for assessment that can be freely chosen by the learner. The tool presents assessment items related either to the goal competences

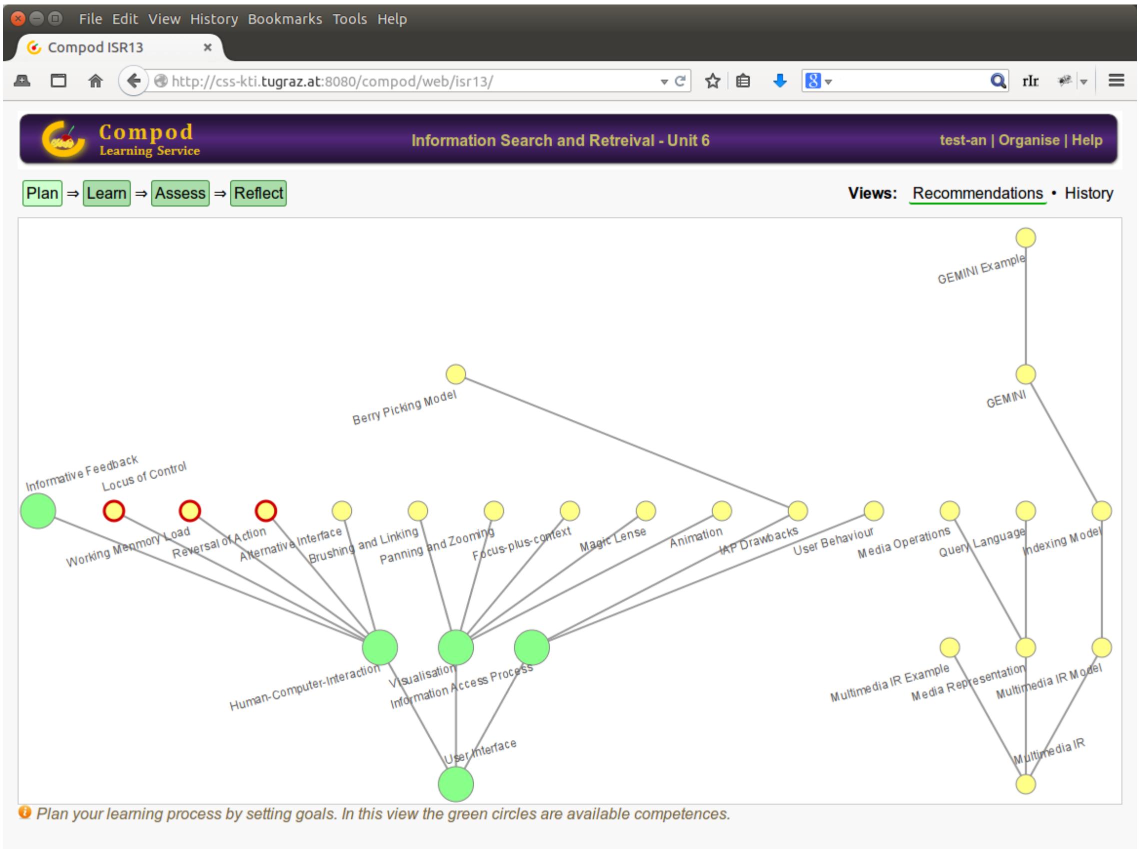


Figure 6.2: This image displays the planning and goal-setting tool with available competences (in green) and goal competences (red border).

or to visited learning objects (Figure 6.4). Therefore, the learner can choose to use the goal-setting feature and do the assessment according to these goals or to omit the goal setting and do the assessment according to the visited learning objects.

The reflection tool presents the learning progress of the learner (Figure 6.5). It displays an overview of the learning progress over time, which is depicted as a green line representing the proportion of available competences after each learning cycle. The proportion is calculated as the number of available competences divided by the number of all competences multiplied by 100. Furthermore, it displays the proportion of correctly (green bars) and incorrectly (red bars) answered assessment questions. Absolute numbers are available to the learner through the tooltip. The tool can also display the number of visited learning objects in relation to the selected competence goal and assessment items, if the learner selects the "Learning Behaviour" view.

User scenarios

From a self-regulated learning perspective, the proposed way of using this interface and thus the Compod system is to start with the goal-setting tool and then use the learning tool, the assessment tool, and the planning tool. This sequence should be reiterated until all competences have been acquired. For example, learner X adds three competences to her current learning goal. Then she navigates to the learning tool where she gets recommendations (highlighted with red borders) for learning objects that teach these competences. The learner visits these learning objects and learns

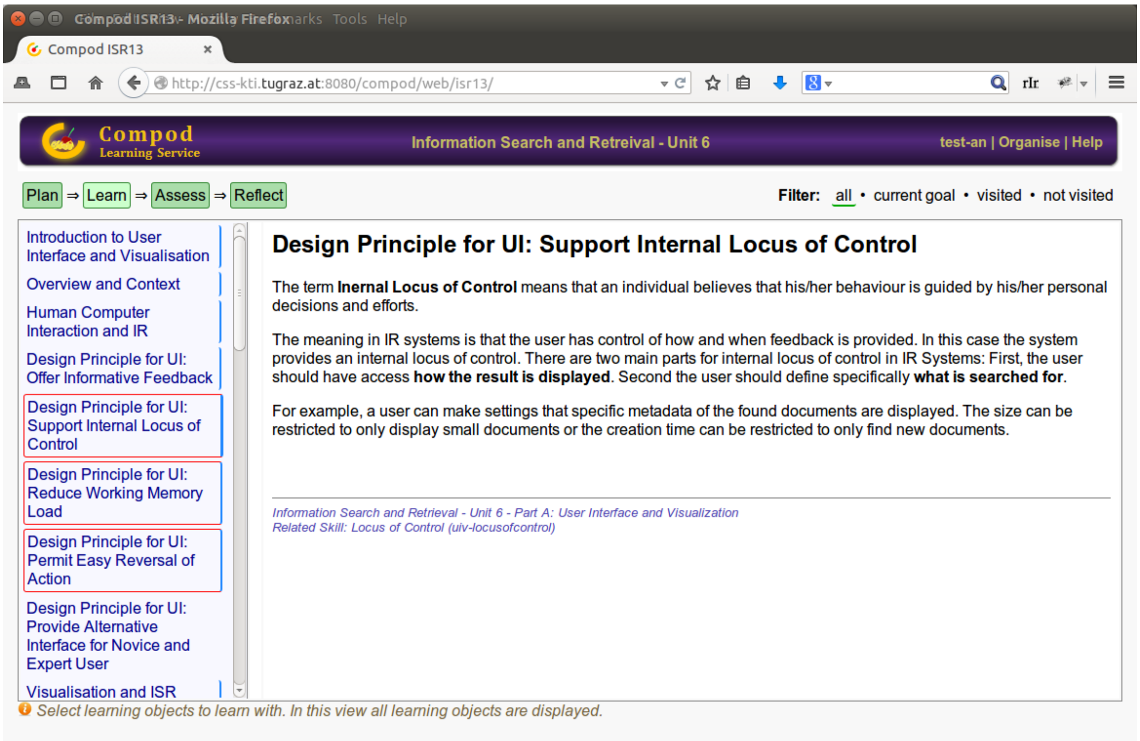


Figure 6.3: This image displays the learning tool with a list of learning objects (recommended LOs with a red border and the visited LOs with a blue line.

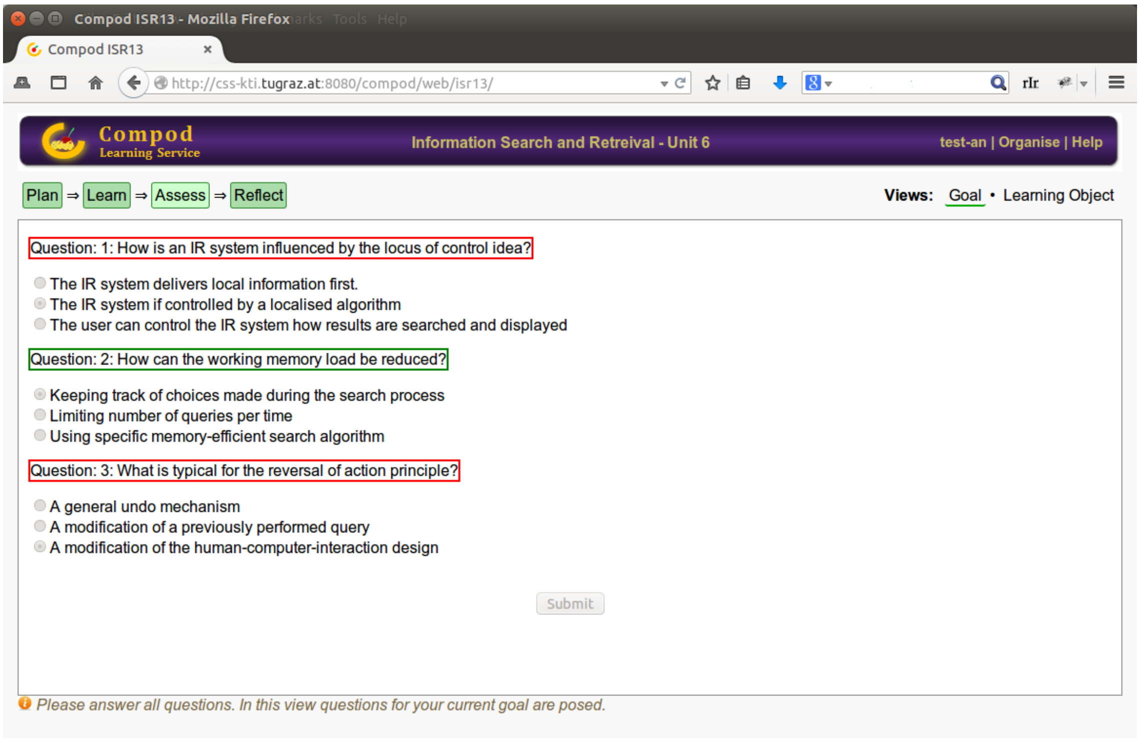


Figure 6.4: This image shows the assessment tool with multiple choice questions. Correctly answered questions are rendered with green border.

the content. After learning, she navigates to the assessment tool where she gets assessment items related to the three competences in her current goal. She answers these items and it turns out

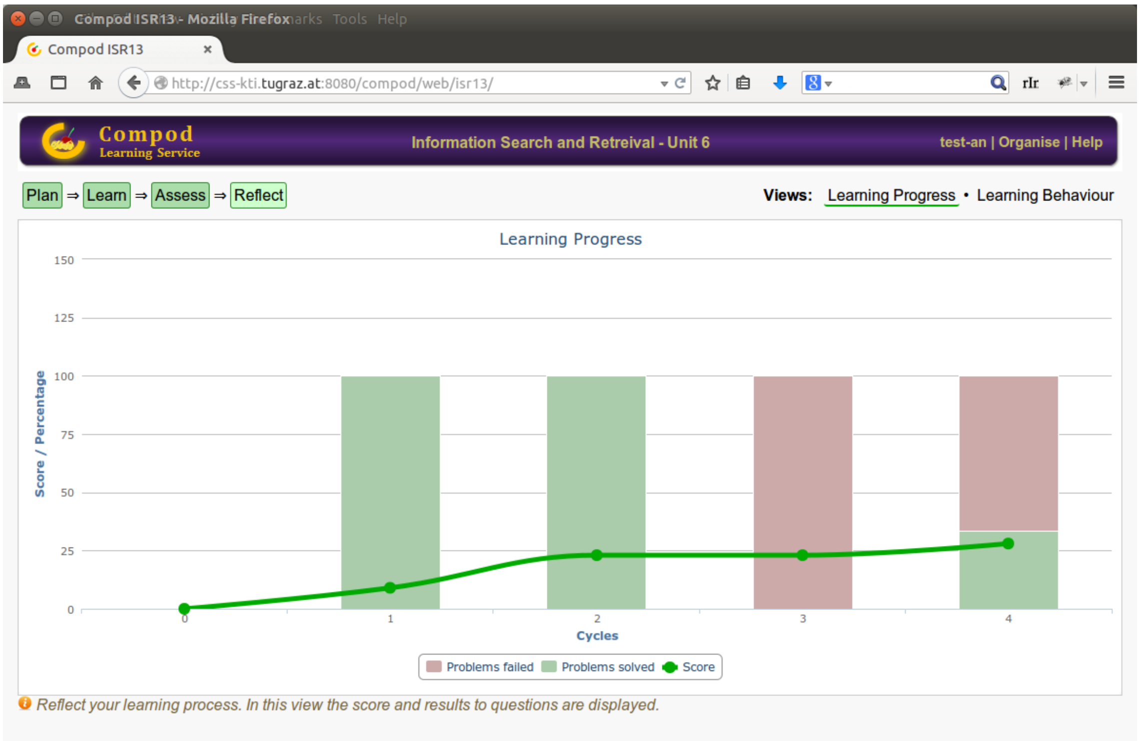


Figure 6.5: The reflection tool is displayed in the screenshot outlining the learning progress.

that one answer is wrong and the others are correct. This information is immediately shown by putting green borders on the questions with correct answers and a red border on the question with the wrong answer. The learner then navigates to the reflection tool where this first learning cycle (iteration) is shown. The average competence level (number of available competences divided by the number of all competences) is depicted as a progressing line. Further, the numbers of visited learning objects and results on the assessment items are shown for this first cycle. After completing this cycle, the learner navigates again to the planning phase. Now the competence map still shows the previous competence goal (highlighted with red circles), but also shows the available competences (green circles) because of mastering assessment items in the previous cycle. Therefore, the learner can modify her learning goal. For example, she will remove the available competences from the current goal, keeping the competence where she failed in the previous cycle and adding two new ones. The remainder of this cycle is processed as before.

Though the case described above follows the self-regulated learning process model, learners can still choose to follow different learning paths and navigation behaviour. For example, learner Y prefers not to navigate through this whole cycle all the time so she navigates to the learning tools and starts learning with some of the learning objects. After a while, she navigates to the assessment tool and gets questions related to the visited learning objects. She completes the assessment with mostly correct answers and one wrong item. She then navigates back to the learning tool where she can see which learning objects teach the missing competences (this is a special view in the learning tool). The learner iterates this combination of the learning and assessment phase several times. From time to time, she also navigates to the goal-setting tool where she gets an overview of her current knowledge state (available competences).

Both cases describe a self-regulated learning behaviour, though these two learners pursue different strategies. Both are in control over their learning process and freely choose their learning behaviour. While learner X explicitly sets current goals and accepts respective personalised scaffolding strategies, learner Y omits the explicit goal setting and chooses individual learning objects directly and creates an individual learning path through the learning objects. Learner X explicitly uses the reflection tool for feedback, but learner Y accepts feedback from the goal-setting tool where available competences are highlighted.

6.4 Authoring Tool

This section describes the tool for creating and authoring domain models. As mentioned above, domain models formally describe and structure learning subject domains and make them available for the technical use. They build the basis for the learning approach based on CbKST, SRL, and AEH. The core components of the domain model are competence definitions, references to learning objects, and assessment items. Furthermore, they include the prerequisite relations between competences, as well as their relations to learning objects and assessment item.

Basically, the creation of a domain model consists in three steps. First, the competences are defined and related to each other through prerequisite relations. Figure 6.6 shows a screenshot of the tool where competences are defined. Buttons for adding, editing, and removing competences and prerequisite relations are on the left side. Adding prerequisite relations take into account that a prerequisite structure adheres to the principle of transitivity. Thus, only those competences can be added as prerequisite competences, if they are not prerequisite to a prerequisite competence. Competences that are assigned to learning objects have blue borders and competences that are assigned to assessment items have red borders.

The second step consists in the definition and references to learning objects (see Figure 6.7). Learning objects are either references to Web pages or resources of VLEs. For example, an experiment in a VRLE can be a learning object, if it can be referenced with an identifier. Learning objects can be added, edited, and removed. Furthermore, assignments to competences can be made, meaning that they convey or teach these competences.

Finally, assessment items are defined (see Figure 6.8). Assessment items can be references to resources of an external VLE that is capable of posing these questions to the leaner and sending the results to the Compod service. The other option is to define multiple choice question that are stored in the domain model. Also in this case the external VLE has to render these questions and send the results to the Compod service. Similar to learning objects, assessment items can be added, edited, and removed. Assignments to competences are done meaning that they test the assigned competences.

6.5 Course Tool

The course tool presented in this section gives an overview of the learner performance in relation to a domain model. The main goal of this tool is to give an insight in the activities and competences attainment of learners. The tool is dedicated to teacher or tutors, but could also be used by learners, in order to compare the own performance with others.

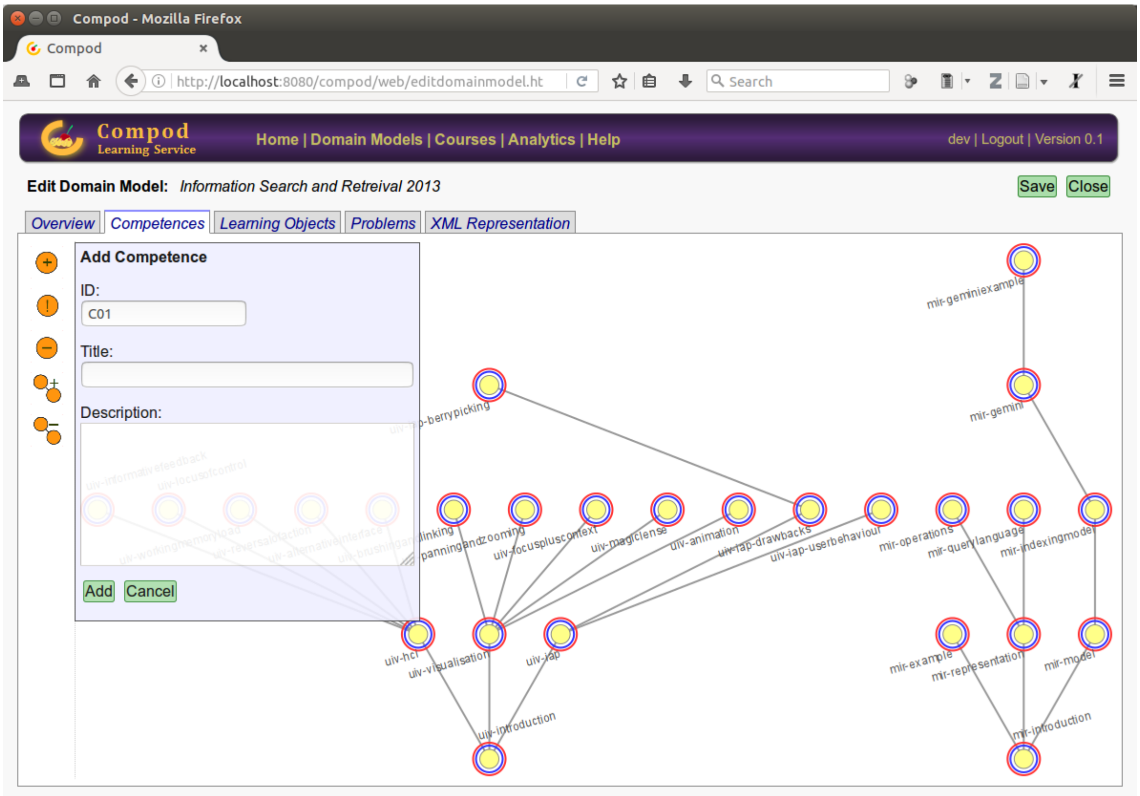


Figure 6.6: Compod authoring tool: Competence structure

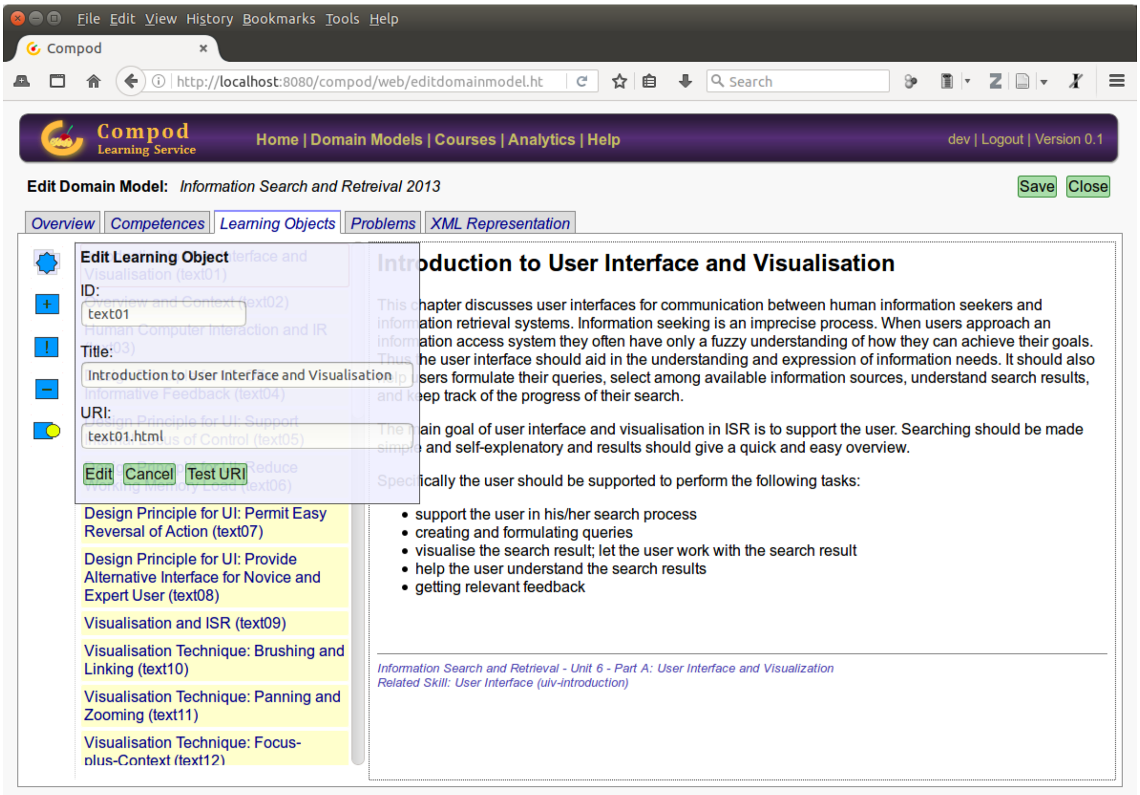


Figure 6.7: Compod authoring tool: Learning objects

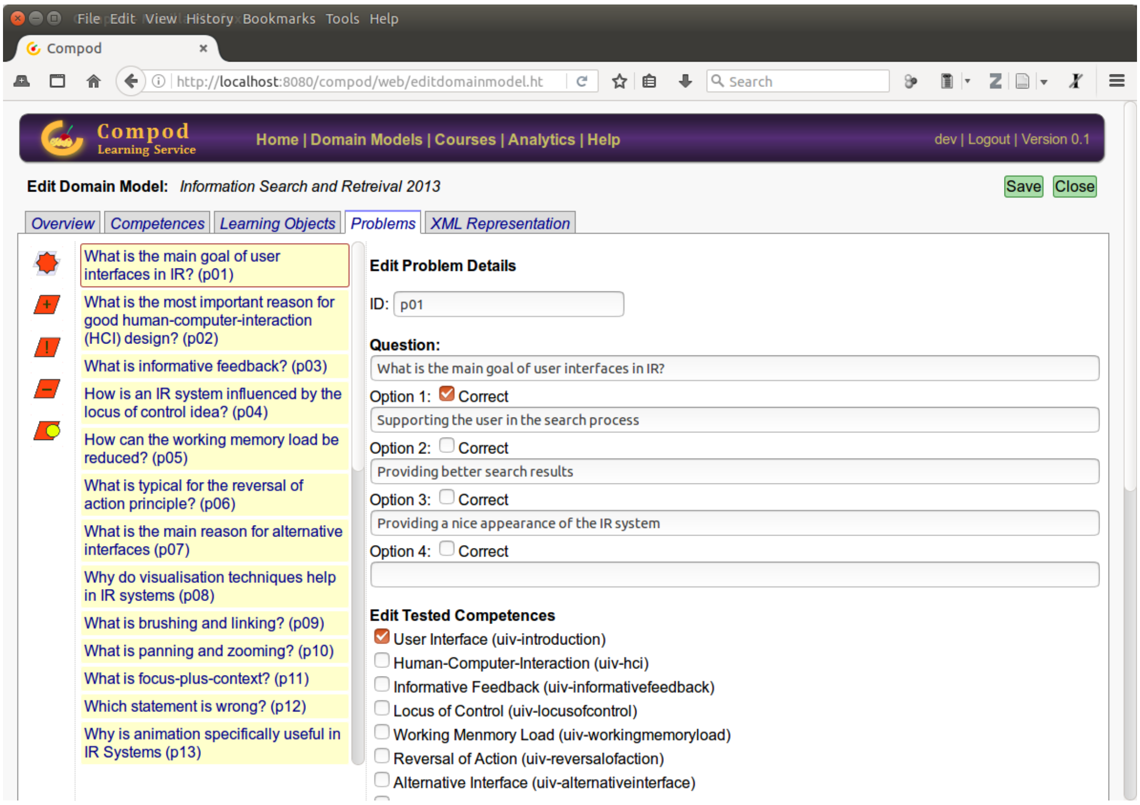


Figure 6.8: Compod authoring tool: Assessment items

The tool provides five different views on the performances of learners in relation to a selected domain model. The first view shows for each learner the average competence probability value and the average numbers of visited competences through learning objects, solved assessment items, and failed assessment items (see Figure 6.9). Visiting a competence means that a learning object teaching this competence is visited. The second view shows for each leaner the average numbers of solved assessment items and failed assessment items (see Figure 6.10). The third view shows for each competence the average probability values of the learners, and the average numbers of visits of learning objects, solved assessment items, and failed assessment items (see Figure 6.11). The fourth view shows for each learning object the average number of visits (see Figure 6.12) and the fifth view shows for each assessment item the average number of visited solved and failed assessment items (see Figure 6.13).

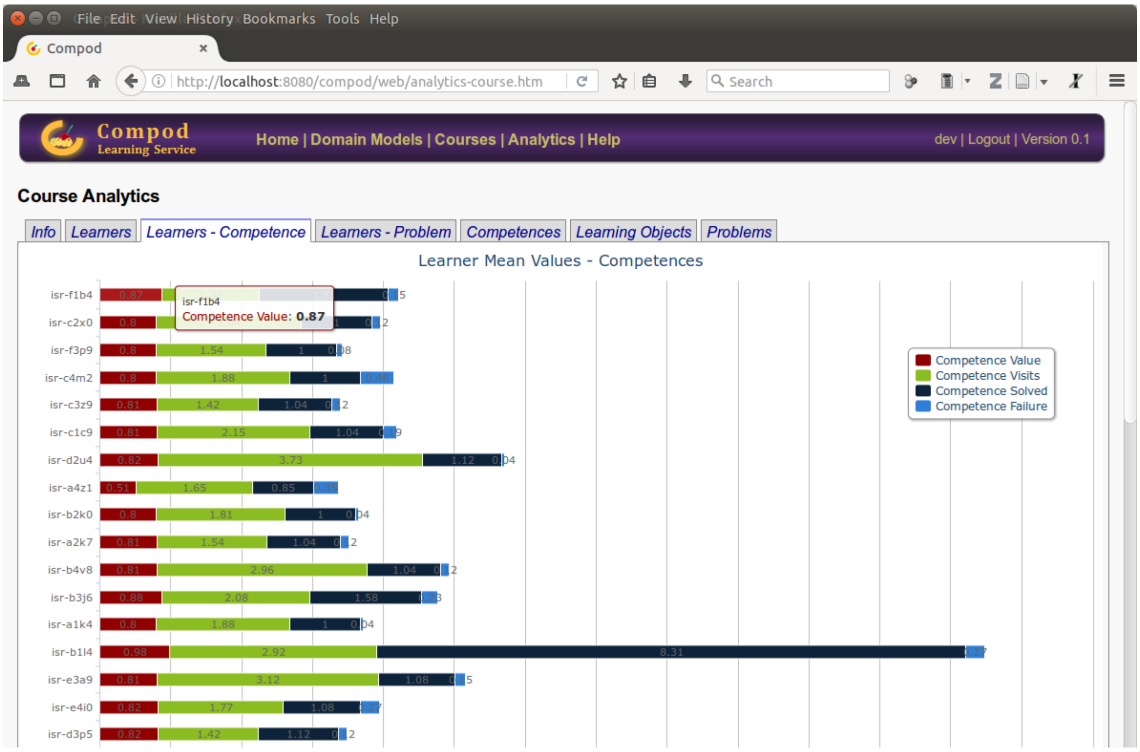


Figure 6.9: Compod course tool: Competences of learners

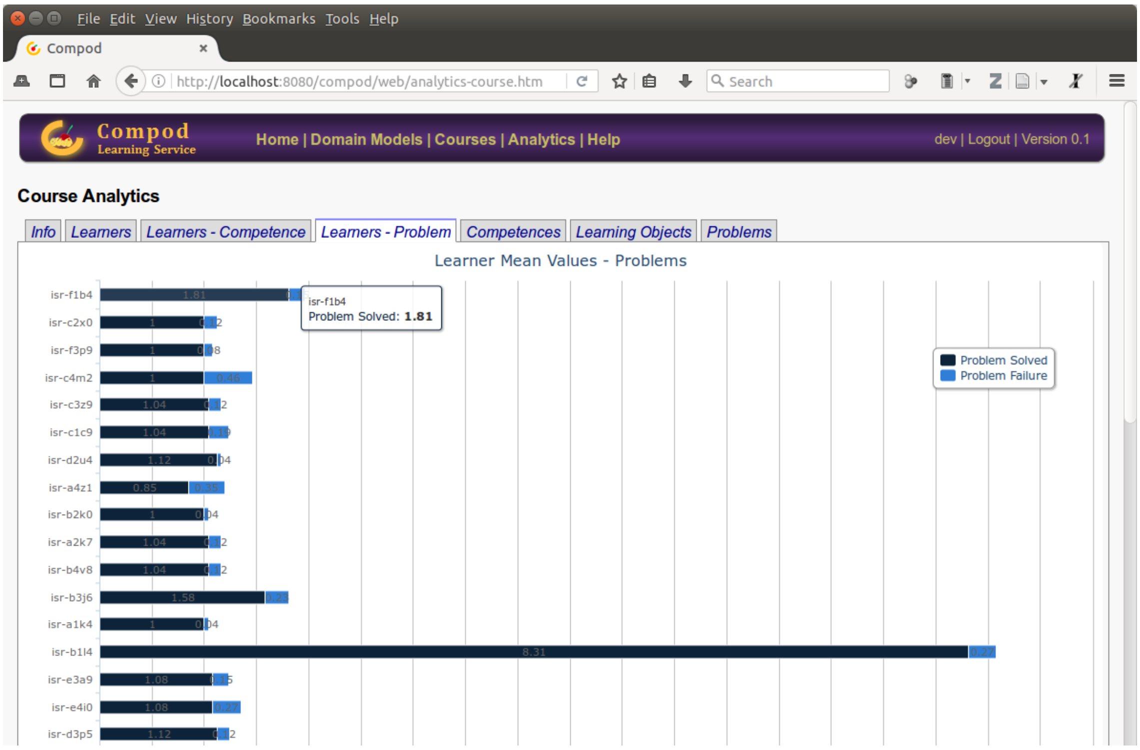


Figure 6.10: Compod course tool: Assessment items of learners

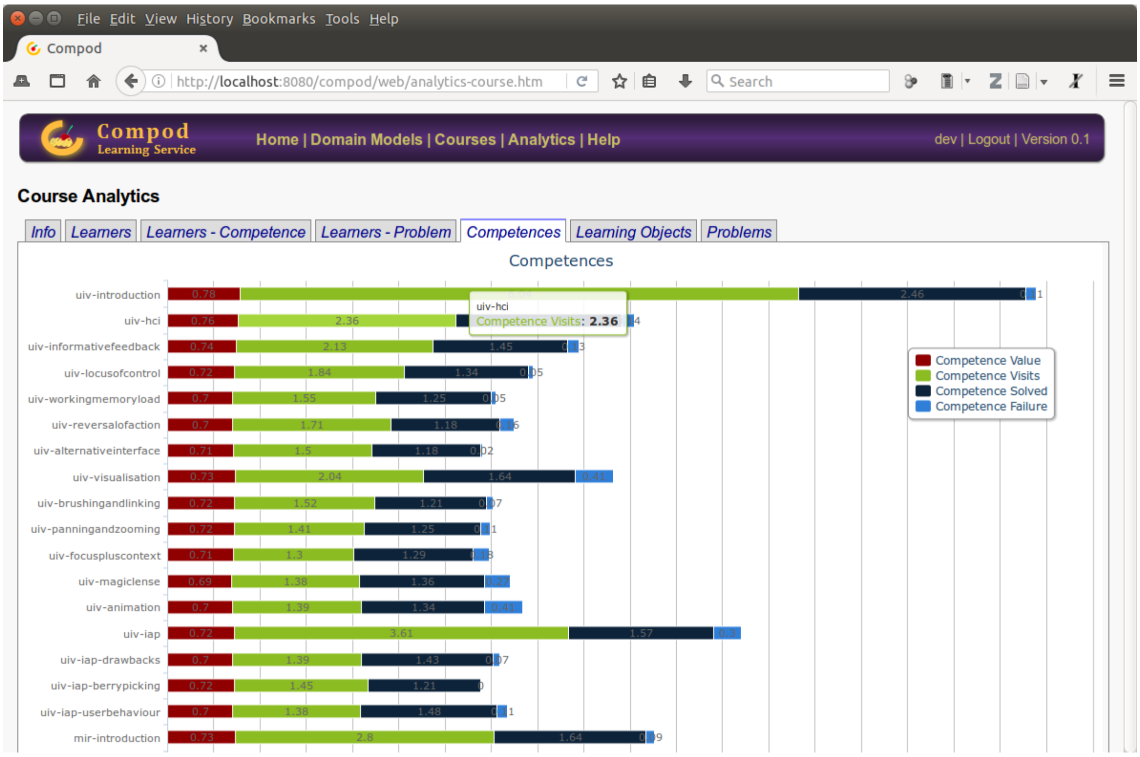


Figure 6.11: Compod course tool: Competences of course

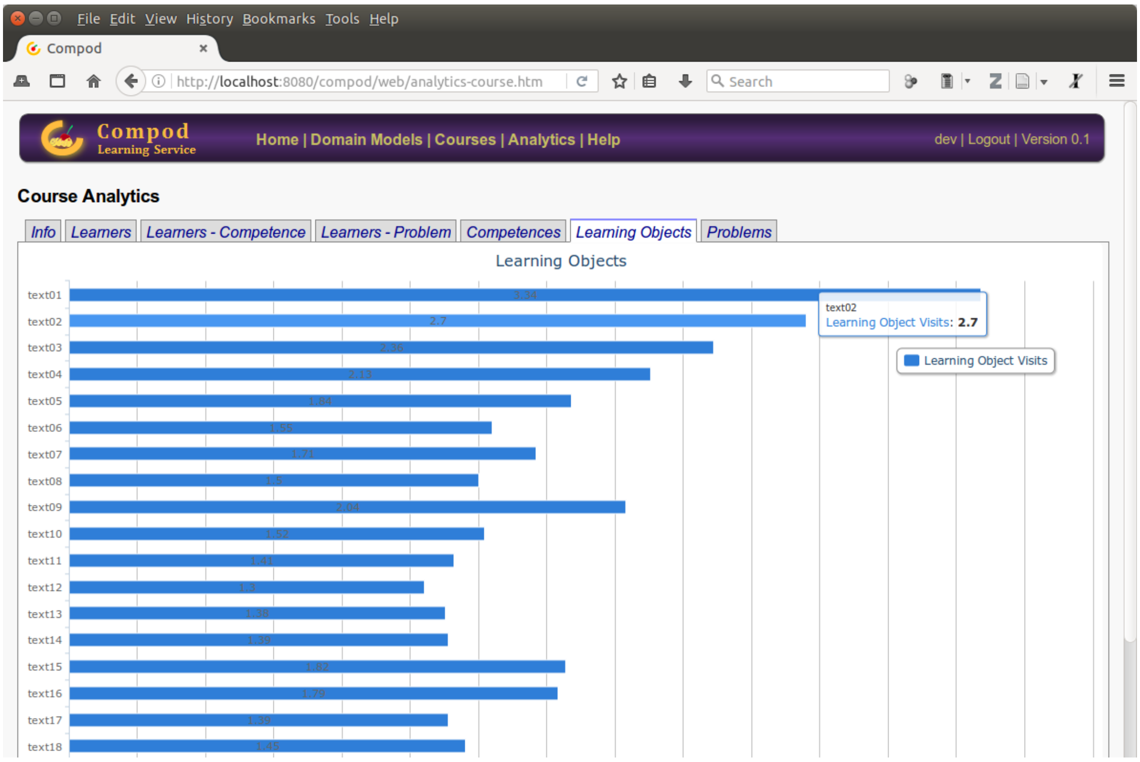


Figure 6.12: Compod course tool: Learning objects of course

6.6 Discussion

This chapter presents the technical framework that includes the technical design and implementation of the Compod system. It follows the conceptual framework described in the last chapter,

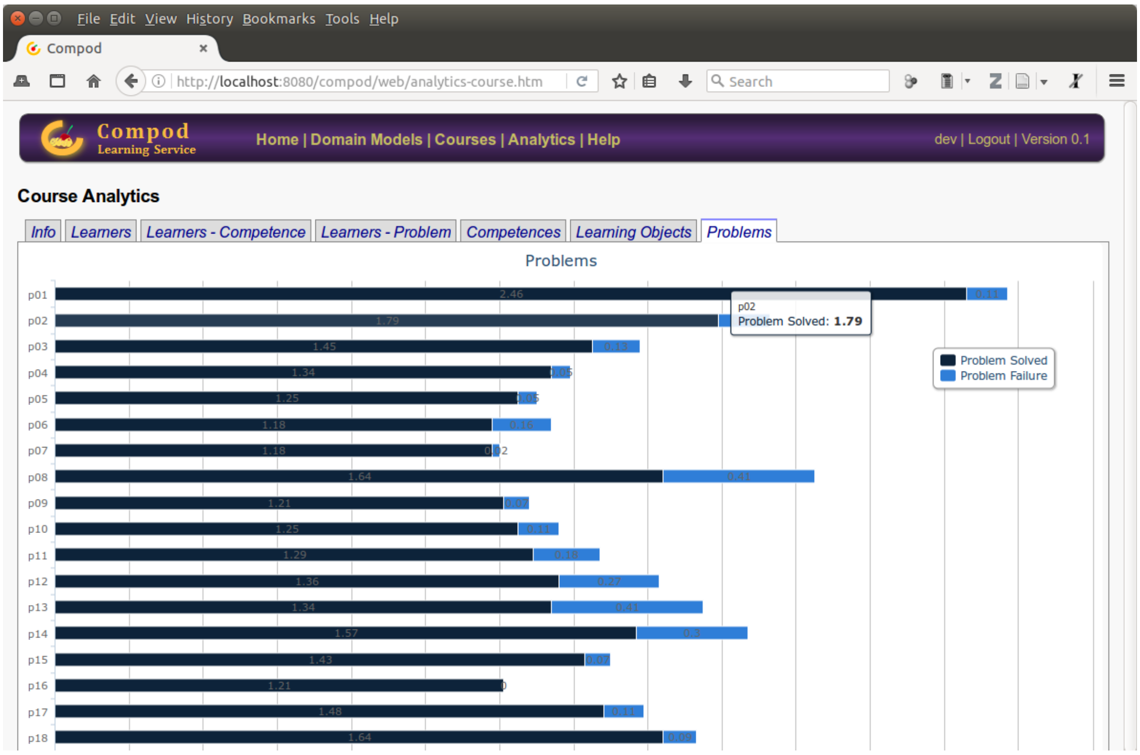


Figure 6.13: Compod course tool: Assessment items of course

which ground it the theoretical basis presented in Chapters 3–4. In this way, the technical development is driven by theoretical learning concepts including AEH, SRL, and CbKST. Thus, the developed approach and software is grounded on a psychological and pedagogical basis. This is important considering the fact that it is dedicated the educational sector.

A demonstration of the learning approach is achieved through the development of the Compod VLE, which serves as a reference implementation for this purpose. While not all features and possibilities are included in this VLE, it still demonstrates the core idea represented in the conceptual framework. It is also used as a testbed for the evaluation of the conceptual framework (see Chapter 8).

The technical framework also contributes to the research field of Learning Analytics (LA). Monitoring the leaner and using learning traces, in order to make it beneficial is a major aim of LA. In our case, the leaner activities are constantly tracked and this information is used for recommendations and visual feedback. Thus the learner benefits from the analysis of the own learning traces. Furthermore, this the tracking information is also used for group inspection that can be used by teachers, tutors and learners. While teacher and tutors get an overview of the class and insight in specific problems (e.g. failing to solve a certain assessment item), learners can use it for comparison with the peers.

Another main characteristics of the technical framework is its flexibility towards external VLEs. It is a main goal to open up the learning approach designed in this work to other VLEs that can make use of it and integrate it into their own environment. This is achieved through the service-oriented architecture on the one hand and a flexible learning approach on the other hand. Especially, the latter allows external VLEs to adapt it to the own inherent learning approach, as it can be used partly and has not to be used exactly in the way as it is defined.

The next chapter demonstrates this flexibility. Different VLEs are presented where the Compod service and learning approach are used in different ways. Each of them use other parts of the conceptual framework, in order to smoothly integrate it in the own learning approach.

Chapter 7

Application in Virtual Learning Environments

This chapter demonstrates how the conceptual framework with its learning approach and the Compod service has been used in five Virtual Learning Environments (VLEs). These VLEs are of different types as described in Chapter 3, namely Intelligent Tutoring System (ITS), Learning Management System (LMS), Personal Learning Environment (PLE), and Virtual Reality Learning Environment (VRLE). The integration of the learning approach and the Compod service proof the their flexibility. This also highlights that both developed framework and software can be used in further VLEs.

All the applications in the five VLEs are published in scientific peer-reviewed journal and conference proceedings (Albert et al., 2008; Dimache et al., 2015; Hockemeyer et al., 2009; Kopeinik et al., 2014; Nussbaumer, 2008; Nussbaumer, Gutl, & Neuper, 2010; Nussbaumer, Gütl, Albert, & Helic, 2009; Nussbaumer et al., 2008; Steiner et al., 2009). Thus the individual application will not be described in detail here, but the respective publication is referenced at the beginning of each section. Furthermore, these sections also use text fragments and images from these publications.

7.1 CbKST Tools and iClass

The section includes text fragments from own contributions in peer-reviewed conference and journal publications (Albert et al., 2008; Nussbaumer, 2008; Nussbaumer et al., 2008; Steiner et al., 2009). More details can also be found in these publications.

The iClass[1] research project aimed at developing a PLE that allows the leaner to freely navigate and learn, but getting support at the same time. It tried to find a balance between "the system decides everything" and "the learner decides everything". In order to harmonise Self-regulated Learning (SRL) with traditional adaptation and personalisation techniques, a new pedagogical model has been defined (Aviram et al., 2008). The key pedagogical process of this model is self-regulated personalised learning (SRPL). This process aims at embedding personalisation in

[1] iClass is a FP6 research project funded by the European Commission

SRL. Hence, SRPL intends to provide learners with the opportunity to self-regulate their learning process and supporting them in this self-personalisation through adaptation technologies.

In order to realise this approach, a PLE has been created that provided learning tools for planning, learning, assessment, and reflection. Adaptation features have been achieved through intelligent and distributed content repositories, where learners could choose from recommended learning objects.

The contribution that the work described in this thesis brings in, consistes of four learning tools that provide a balance between adaptation and self-regulated learning. In addition to the other tools of the iClass project, these tools allow for planning, learning, assessing, and reflecting based on Competence-based Knowledge Space Theory (CbKST) structures and algorithms. These tools addressed both SRL meta-cognitive processes and learning support through CbKST.

The planning tool (see Figure 7.1) allows to chose competences from a prerequisite structure and to arrange them in a sequence. Furthermore, learning objects can be retrieved from the system-wide content repository that fit to the selected competences. Thus a plan of competence development and learning objects is created. The learning tool allows to visit the learning objects of the created plan. Then the assessment tool allows for conducting a knowledge assessment taking into account assessment items that test the selected competences. The assessment algorithm is based on CbKST competence assessment. Finally, the reflection tool displays the visited learning objects and assessment items, and presents the gap between goal competences and achieved competences (as result from the assessment).

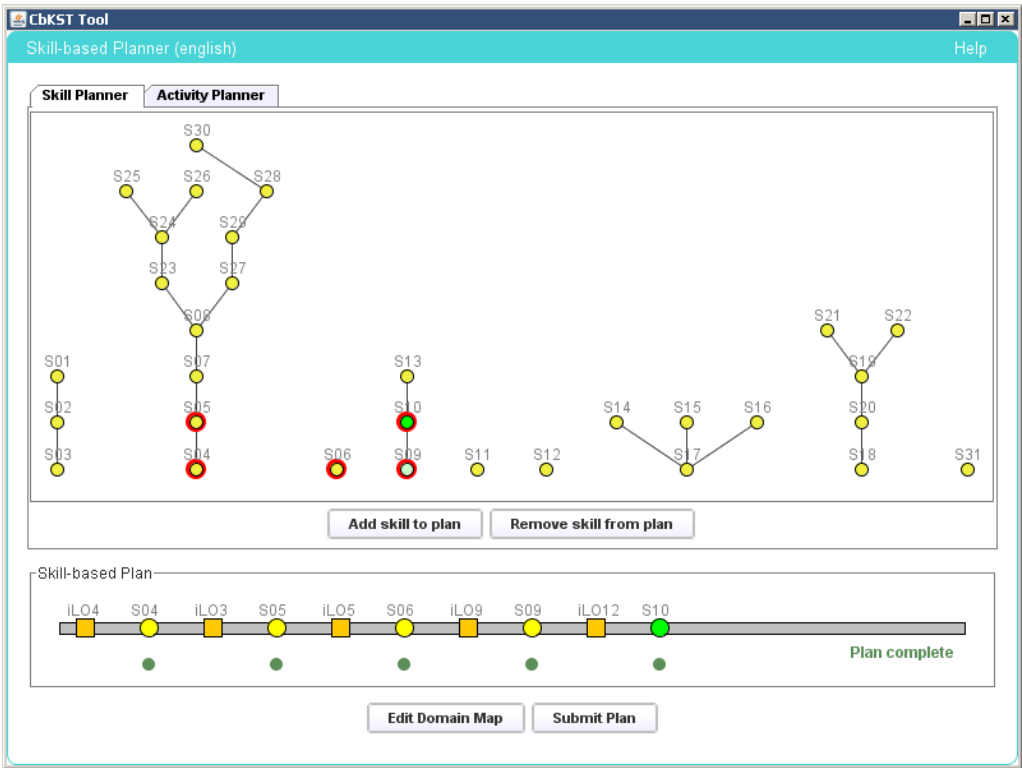


Figure 7.1: The image shows the Skill-based Planner of the iClsas system. The picture is published in Steiner et al. (2009).

From a technical point of view, the contribution consists in the creation of these tools as Java applets with the iClass system in the background that is responsible for storing domain and user information (see Figure 7.2). After this project, the Compod service and Compod VLE were inspired by this approach. The visualisation and user interface part of the tools were implemented in the Compod VLE and the algorithms and data storage was implemented in the Compod service.

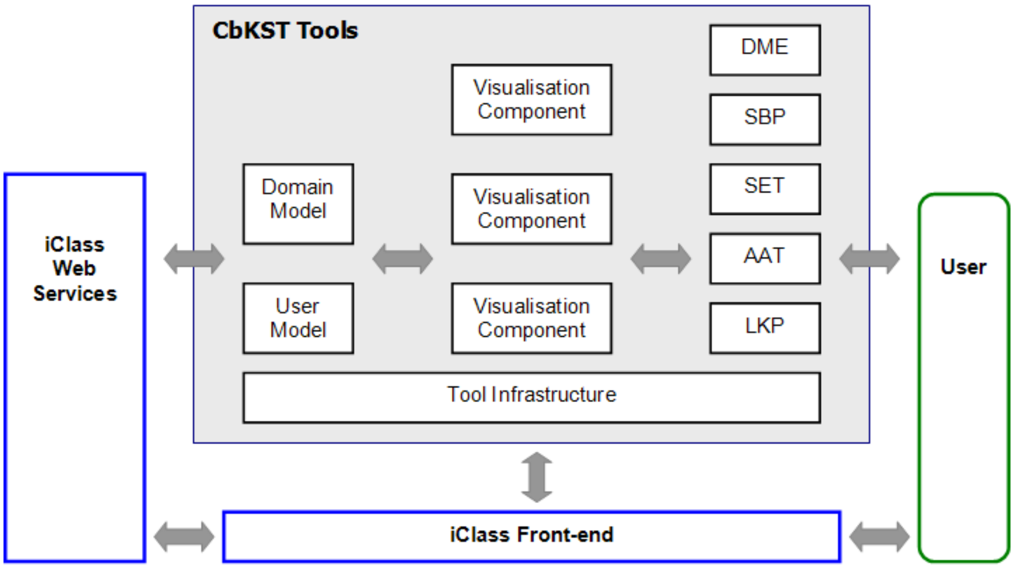


Figure 7.2: The image shows the architecture of the CbKST tools embedded in the iClsas system. The picture is published in Steiner et al. (2009).

A summary and overview of this VLE application in connection with Compod is given in Table 7.1.

Table 7.1: Summery of CbKST tools and iClass.

VLE	PLE
Target users	School
Pedagogical approach of VLE	Self-regulated personalised learning
Compod approach and support	Support for SRL based on CbKST including assessment, goal setting, planning, and reflection.

7.2 Learning Landscape in SecondLife

The section includes text fragments from own contributions in a peer-reviewed conference publication (Nussbaumer et al., 2009). More details can also be found in this publication.

Learning Landscape (LearnScape) is an application developed in SecondLife that demonstrates the Compod approach in a Virtual World (ViWo). It uses SecondLife as a learning environment with all the features that this ViWo application has (e.g. multi-user approach and user-created content). In this approach the learner can immerse into a virtual learning landscape consisting of learning objects and is guided by highlighting a path through the landscape. The path creation is based on competences which are assigned to learning objects. Principles of the SRL approach is realised by visualising the learner model in 3D space and by giving the learner freedom for the own learning process. A screenshot learning landscape is given in Figure 7.3.

Realising a learning path is done by successively highlighting one learning object after another one. This mechanism bears also the possibility to highlight more objects at the same time if they are equal (at the same level) regarding the logical sequence. In this way the learner can freely choose between them, which gives more control to the learner. A further level regarding self-regulated learning is obviously given by the fact that the learner can freely move in 3D space and can deal with any learning object in the learning landscape independent of the highlighting state. Obviously this is a very natural way of providing self-regulated learning possibility, since it comes from the general system design and is not an explicitly created system feature.

A further element of the conceptual design is a feedback object which gives information to the learner about the learned skills. As pointed out above, by using a domain model for content structuring, skills are defined including prerequisite relations between them. The skills of a domain and their prerequisite structure are represented in 3D space as a 3D skill structure model. If a learning object has been done than specific competences have been taught by this learning object. These skills can be highlighted in the skills structure model by changing the colour of the respective skills. For example learned skills can be green, the other skills can be grey.

The technical implementation follows the Compod approach. The Compod service in the background manages the domain model that provides references to the learning objects in SecondLife. Furthermore, it holds and updates the user model if a learner visits a learning object. The implementation in SecondLife is done by the scripting the learning objects and the visual competence model. If a learner has visited a learning object, then this has to be indicated by clicking on the marker object attached on the learning object. The marker object changes its state (colour) and sends a message to the Compod service. Then the Compod service is asked for next recommended learning objects, which leads to the update of the marker objects. The same happens with the visual competence model.

A summary and overview of this VLE application in connection with Compod is given in Table 7.2.

Table 7.2: Summery of LearnScape in SecondLife.

VLE	VRLE
Target users	not specified
Pedagogical approach of VLE	Self-regulated learning within a virtual reality environment
Compod approach and support	Support for SRL based on CbKST including planning, and reflection

7.3 Adaptation in ISAC

The section includes text fragments from own contributions in a peer-reviewed conference publication (Nussbaumer et al., 2010). More details can also be found in this publication.

Another VLE to demonstrate the Compod approach is the ISAC[2] computer algebra system.

[2] http://www.ist.tugraz.at/isac/

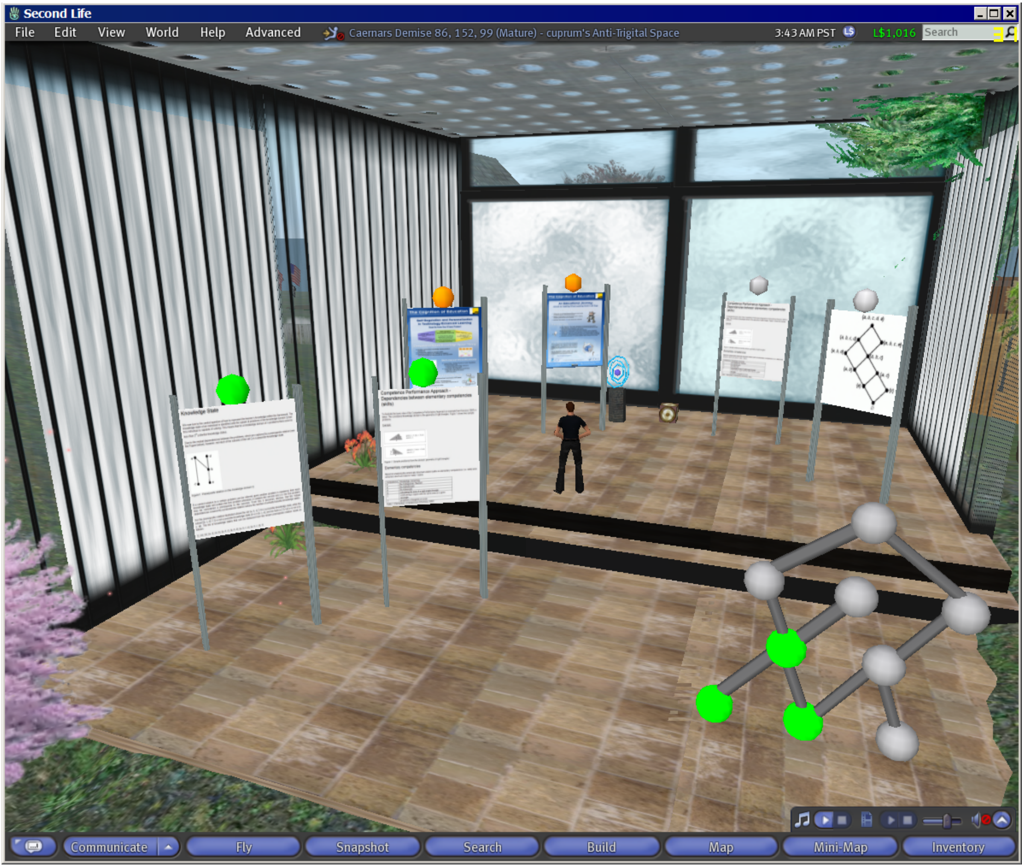


Figure 7.3: The image shows a learning landscape in SecondLife (the picture is published in Nussbaumer et al. (2009)).

ISAbelle for Calculations in Applied Mathematics (ISAC) is a single stepping system which is able to proof individual steps of the user's calculations. In contrast to other assessment systems, ISAC not only "knows" if the result calculated by the user is correct or not, ISAC has also the possibility to introspect the several steps. For example, if a result is not correct, but several steps are correct and at a certain step the user fails, than ISAC can provide help for exactly this step though explanation of the underlying and needed theorem.

The interesting part of this approach is, that ISAC has available a set of mathematical theorems and can apply them on expressions. When solving a calculation step by step, it is known afterwards which theorems were needed. For different calculations different theorems are needed and in this way the calculations can be characterised by the applied theorems. Being able to apply a theorem can also be interpreted as a competence. So a connection is made between formally expressed theorems which can be used by computer systems and the competences of humans.

Following this consideration, the Compod approach has been used with ISAC. In a student's project that followed the concept of this thesis, an implementation has been made for integrating the Compod service with ISAC. Adaptive assessment and learning path creation are applied meaning that the sequence of calculation tasks are determined by the Compod service. Since the calculation tasks can function as both learning objects and assessment items, both algorithm of Compod can be used for learner guidance. Furthermore, goal setting in terms of competences (theorems of ISAC) can be applied, in order to influence the learning paths. ISAC benefits from this approach, since a user model approach and an efficient algorithm for adaptive assessment can be integrated with ISAC without much effort.

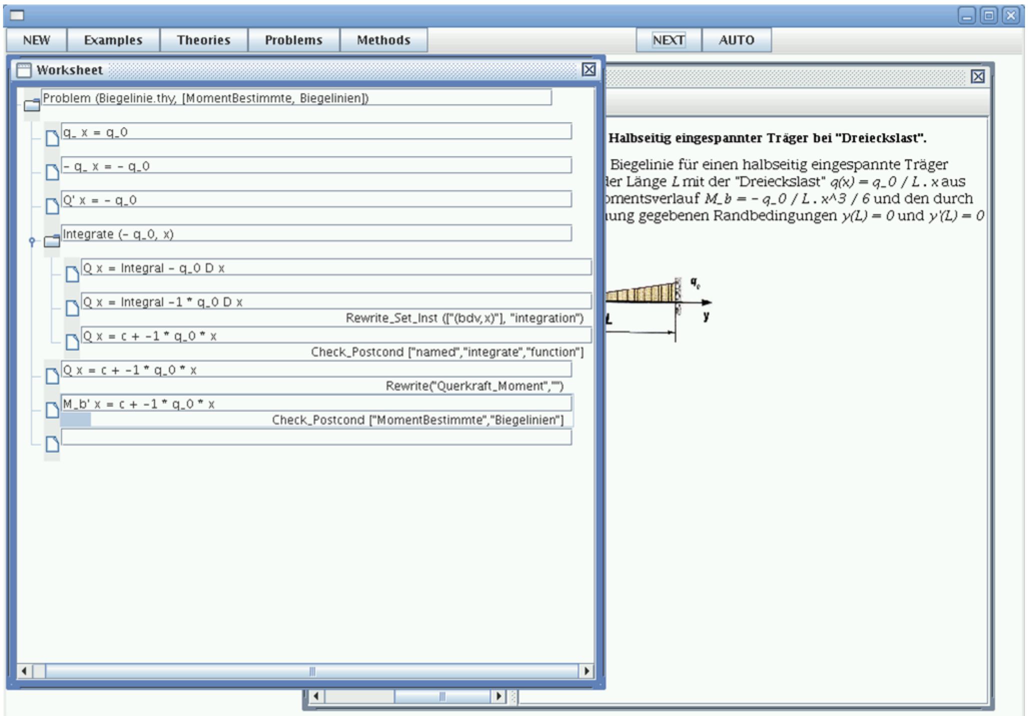


Figure 7.4: The image shows an assessment item in the ITS ISAC.

A summary and overview of this VLE application in connection with Compod is given in Table 7.3.

Table 7.3: Summary of adaptation in ISAC.

VLE	ITS
Target users	School
Pedagogical approach of VLE	Tutoring
Compod approach and support	Support for adaptive assessment and learning paths

7.4 Competence Assessment in MedCAP

The section includes text fragments from own contributions in a peer-reviewed conference publication (Hockemeyer et al., 2009). More details can also be found in this publication.

The MedCAP[3] research project aimed at the provision of a medical training programme for spinal anaesthesia. This was done by using both Moodle as LMS that provided a theoretical course on spinal anaesthesia and a haptic simulator that was used to insert a needle in with realistic haptic feedback. While Moodle poses questions in a traditional way, the haptic simulator translates user actions (inserting the needle) into results of assessment items (if the needle was inserted correctly). In addition to Moodle and the haptic simulator, competences have been defined that are needed

[3]MedCAP is a research project funded under the Life-Long-Learning programme of the European Commission

for spinal anaesthesia. Furthermore, they are structured with prerequisite relations following the CbKST approach.

The contribution related to this thesis consisted in the creation of a Web service that performed that competence assessment. It accepted the results of the assessment items coming from the Moodle application and the haptic simulator. Though the different nature of these types of assessment items, they were treated identically, except that they are assigned to different competences. The competence assessment was performed through the classical algorithm for knowledge assessment that was then mapped to the assigned competences. However, in contrast to the classical assessment, assessment items were not adapted. A predefined sequence of assessment items were used as basis from which the CbKST service responded which item should be omitted.

From a technical point of view, the service was created as Java servlet application for Tomcat. The service included the management of user and domain model that provided references to the items of Moodle and the haptic simulator. The service accepted results from the assessment items and provided information which item would be next and if an item can be omitted. The result of the assessment is visualised in graphical way with available competences highlighted. The overall architecture of this approach is depicted in Figure 7.5.

A summary and overview of this VLE application in connection with Compod is given in Table 7.4.

Table 7.4: Summery of competence assessment in MedCAP.

VLE	LMS
Target users	Vocational area (medical doctors)
Pedagogical approach of VLE	Training
Compod approach and support	Support for adaptive assessment and reflection

7.5 SRL with Moodle in INNOVRET

The section includes text fragments from own contributions in a peer-reviewed conference publication (Kopeinik et al., 2014). More details can also be found in this publication.

The fifth context where the Compod service was tried out, is the INNOVRET[4] research project. This project aimed to provide an online training solution for heat pump installers with the LMS Moodle. In this project a Moodle plugin was created (by the people involved in this project) that was connected to the Compod service.

A self-regulated learning approach has been developed that is similar to the one used in this thesis. This approach consists of a cyclic process of a planning phase, a learning phase, and an assessment phase. In contrast to the learning approach of this thesis, the planning phase consists in the selection of a predefined profile that includes a set of competences to be learned. After selecting the profile, the learner undergoes an initial assessment. Then the learner gets recommendations for learning objects fitting to the current competence state. When the learner feels

[4]INNOVRET is a research projected funded under the Life-Long-Learning programme of the European Commission

comfortable with the acquired knowledge from the learning objects, the reflection tool can be chosen. This tool presents metrics of the learning history. Then the cycle returns to the assessment.

The assessment procedure, the recommendation of learning objects, and the information for the reflection phase is facilitated by the Compod service. The learning objects and assessment items are created in Moodle and references to them are stored in the domain model of the Compod service. While the competence structure is defined with the Compod authoring tool, the assignment of learning objects and assessment items are performed in Moodle by using an interface of the Compod service.

A summary and overview of this VLE application in connection with Compod is given in Table 7.5.

Table 7.5: Summery of SRL with Moodle in INNOVRET.

VLE	LMS
Target users	Vocational area (workers)
Pedagogical approach of VLE	Restricted self-regulated learning
Compod approach and support	Support for SRL based on CbKST including assessment, goal setting, and reflection.

7.6 Discussion

This chapter presents five different approaches where the Compod service and related learning approach is applied in different types of VLEs. The approaches differ regarding the type of VLE, the types of learners, the pedagogical approach of VLE, and which functionality they use from Compod. An overview of these approaches is given in the Tables 7.1–7.5.

The overview in these tables emphasises the versatile application of Compod. It has been applied in the four types of VLEs as described in Chapter 3. These VLEs and the related applications that used Compod followed different pedagogical approaches. The approaches include self-regulated learning (also in a restricted form), tutoring, and training. The target user groups include schools, different types of vocational areas, and higher education (Compod VLE). Also the support provided by Compod is different depending to the respective VLE. While three PLEs mainly used adaptive assessment and adaptive learning path creation, the other two made use of different levels of SRL support.

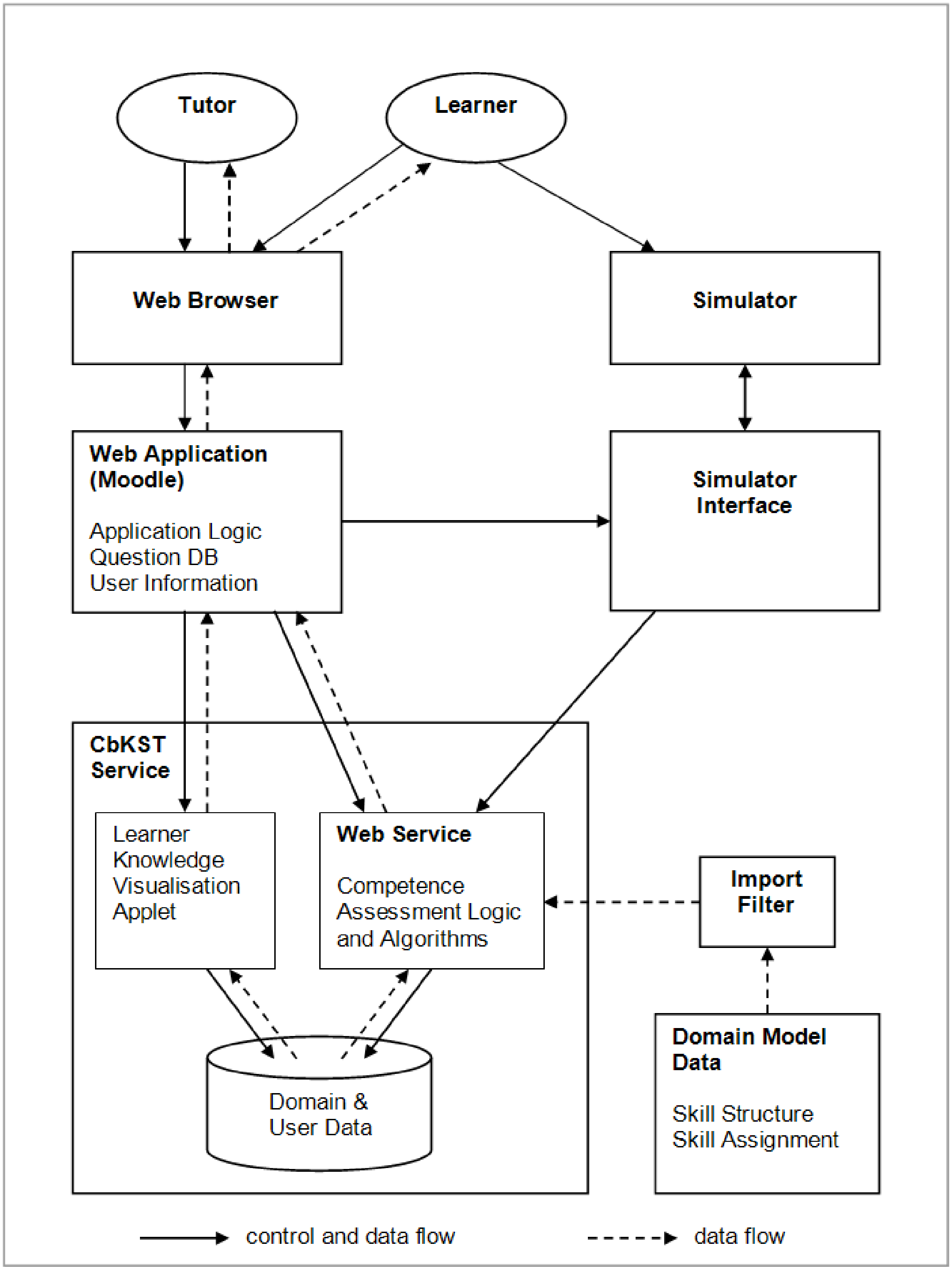


Figure 7.5: The image shows the architecture of the MedCAP system connected with the CbKST service. The picture is taken from Hockemeyer et al. (2009).

Chapter 8

Evaluation Results

This section presents an in-depth evaluation of Compod VLE. As stated in previous chapters, Compod VLE is a reference implementation of an external VLE that uses Compod service. As a main feature, it implements the conceptual framework and related learning approach. Thus the evaluation targets not only the software component, but also the learning approach, the learning outcome, and the usefulness of the visualisations.

The chapter includes the evaluation section from an own contributions (made in collaboration with Eva Hillemann - see Section 1.4) in a peer-reviewed journal publication (Nussbaumer, Hillemann, et al., 2015). Furthermore, it includes fragments from the evaluation section of the INNOVRET evaluation (Kopeinik et al., 2014).

8.1 Compod VLE

The section includes the evaluation section from an own contributions in a peer-reviewed journal publication (Nussbaumer, Hillemann, et al., 2015).

In order to demonstrate the usefulness and applicability of the presented approach and service, the Compod system with its user interface was applied in the context of a university course held at Graz University of Technology. The main purpose of this evaluation was to answer the following questions. While the research questions outlined in the Summary and Resulting Research Questions section led to the solution approach and related system implementation described above, these evaluation questions intend to test these solutions:

- **E1:** How useable and acceptable is the overall Compod system and its user interface? This question addresses two aspects: usability and user acceptance. Usability refers to the issue of whether the system allows the user to achieve a specific goal effectively, efficiently, and satisfactorily. Concerning user acceptance, the main question of interest is whether users find the system acceptable and intend to use it. Research has shown that although a system is technically sound, users often do not intend to use the system because they lack a positive attitude towards system's usage (Davis, Bagozzi, & Warshaw, 1989). Thus, answering this question is an indicator of whether learners will adopt the self-regulated way of learning in future.

- **E2:** Do learners accept and follow the learning approach provided by the Compod system? Do they adopt the self-regulated way of learning? This question refers to whether learners actually use the system and its different self-regulated learning functionalities.
- **E3:** Does use of the Compod system and its underlying learning approach benefit the acquisition of domain knowledge? This evaluation question addresses the learning effectiveness that can be achieved through self-regulated learning with the Compod system.
- **E4:** How do users feel about the visualisations (i.e., goal-setting tool and reflection tool) provided by the system? This question refers to users' perceived benefit of the visualisations provided by the system. This includes questions like whether the visualisations are understandable and suitable for their given tasks, or whether the visualisation types help them to plan or reflect on their learning process in terms of learning effectiveness.

8.1.1 Method

This section presents the method and results of the evaluation study, consisting of two evaluation rounds conducted in 2013 and 2014. We employed a descriptive evaluation study design with a rather formative character aimed at improving the software and the learning approach. In the following sections, the methodology of the evaluation study is first described, and then the analysis of the data collected is given.

Setting

The study was conducted in the context of a university course on "Information Search and Retrieval (ISR)" held at the Graz University of Technology, Austria, in November 2013 and November 2014. This university course is a typical mandatory computer science course in the Master's Program, which guarantees that enough students are available and motivated to participate in research studies. The whole lecture consists of different topics, such as Web Retrieval, Query Languages, or Information Retrieval Models. For one topic, namely "User Interface and Visualisation" about multimedia information retrieval and user interfaces in information retrieval, the Compod system has been used. In order to use the Compod system and its functionalities adequately, the domain model was created by the authors. The domain model consisted of 26 competences structured through prerequisite relations (see Figure 6.2). Furthermore, 32 learning objects and 26 assessment items related to the competences were created. The learning objects included the content conveyed in the lecture on this unit in previous years. The four tools used in this evaluation are depicted in Section 6.3.

Participants

The study was carried out with two groups of Master's students at two points in time. In the first group (winter 2013), 28 students (6 female, 22 male) took part and filled in the evaluation survey. The sample consists of students of Computer Science (20 students), Software Development and Business Management (5 students), and Telematics (3 students). Students indicated that they had a medium pre-knowledge of the subject taught. In the second group (winter 2014), 22 students (4 female, 18 male) participated in the study and completed the evaluation survey. Participants were students of Computer Science (18 students), Software Development and Business Management (2 students), and Telematics (2 students). They indicated that they had an average knowledge in the field taught.

Material

In order to collect and analyse quantitative and qualitative data, a multi-method approach consisting of user model data sources and questionnaire data sources was applied in this study.

User Model Data: For investigating how and in which way students use and apply the system and its underlying learning approach, data on the learning and navigational behaviour of students was recorded as useful descriptive information. Learning behaviour data contains information on the visited learning objects, the responded assessment items, selected goals, and the acquired competences. Navigational data contains log data recording user interaction with the Compod system, or more concretely, which tools were used in which sequence and with what frequency.

Questionnaire: An online survey was created consisting of five short questionnaires allowing for capturing quantitative as well as qualitative feedback from students. The survey was realised and administered using an online survey system. The following main aspects were addressed by the online survey: usability, user acceptance, learning approach and guidance, usability and benefit of the goal-setting tool, and usability and benefit of the reflection tool. The five questionnaires are shown in Chapter B.

For answering the first evaluation question referring to the general usability of the system (E1), the System Usability Scale (SUS) (Brooke, 1996) covering 10 items was used. With respect to user acceptance, which refers to the first evaluation question (E1), a scale of three items covering the main aspects (i.e., perceived ease of use, perceived usefulness, and intention to use) according to the technology acceptance model (Davis et al., 1989) was adapted.

The aspects learning approach and guidance were captured by three items each. These newly created items ask for general level feedback on the usefulness and applicability of the learning approach used by the system. To collect qualitative feedback on these aspects, this section was completed with one open question where participants had the opportunity to give additional feedback and comments. Gathering data on this aspect allows for answering the second evaluation question (E2).

In order to evaluate visualisation types used for the planning (i.e., goal-setting tool) and reflection (i.e., reflection tool) phases and in order to answer the fourth evaluation question (E4), a questionnaire developed in order to evaluate visualisations in the context of digital libraries (Steiner et al., 2014) was adapted (see Table 8.1). Overall, the questionnaire consists of two scales: one (4 items) assessing usability, and the other (6 items) investigating the perceived benefit. Usability consists of the subscales suitability for the task and self-descriptiveness. The perceived benefit scale consists of the subscales metacognition, cognitive load, and learning effectiveness. At the end of the study, participants were asked to provide qualitative feedback on the strengths and weaknesses of the goal-setting tool and the reflection tool.

Each aspect (i.e., user acceptance, learning approach and guidance, goal-setting tool, and reflection tool) – except usability – covered by the survey was assessed with items or statements answered on a seven-point rating scale ranging from strongly disagree (1) to strongly agree (7). Negatively poled items have been recorded for further calculations. Then, for each aspect, a mean

Table 8.1: Subscales on usability (i.e., suitability for the task and self-descriptiveness) and perceived benefit (i.e., metacognition, cognitive load, and learning effectiveness) to evaluate the goal setting tool as well as the reflection tool.

Subscale	Items
Suitability for the Task	I find this visualisation suitable for getting an overview of the current status in the learning process.
	I think the visualisation provides irrelevant information.
Self-Descriptiveness	It is easy to understand this visualisation.
	I find this visualisation unnecessarily complex.
Metacognition	I think this visualisation can help learners reflect on their learning process.
	I think this visualisation supports learners in better planning their learning goals.
Cognitive Load	I think interpreting this visualisation would put additional cognitive effort on the learner.
	I think this visualisation is able to leverage the mental workload.
Learning Effectiveness	I think this visualisation can help learners in accomplishing their goals.
	I think the use of this visualisation will not make a difference for learning performance.

score averaging across the rating scale can be calculated with higher values indicating a better result. For assessing overall usability, we applied the SUS, including statements rated on a five-point scale ranging from strongly disagree (1) to strongly agree (5). The raw data generated from the survey was then computed to an overall SUS score ranging from 0 to 100, with higher values indicting a better result.

Procedure

Master's students were asked to use the system for one week, and were completely free to decide when and for how long to use the system for learning. However, it was mandatory for them to use and to answer enough assessment items correctly in order to collect the required points used for their marks. Of course, they could also use other resources for their learning in addition to the material provided by the Compod system. Previously, accounts for each student had been created separately and sent out to them. Furthermore, students got a general explanation of how to use the system and the evaluation study in a lecture before starting to work with the system. After one week, the system was closed so that the students could not use it anymore. After working with the system, the students were asked to fill in the online evaluation survey.

8.1.2 Results

Results of the learning progress and the tool usage

Since the learning behaviour was tracked by the Compod Service, user model data for each student is available. Though this data was used to support the students during their SRL processes, a post-analysis revealed interesting information about not only the learning effectiveness of the system, but also whether students followed the proposed learning approach. Overall, the data consisted of two types of information: learning progress and navigational behaviour.

Learning progress and knowledge level: The goal of the students was to achieve a score of at least 50 out of 100 points. In order to earn points, they had to answer assessment items correctly. Having available all competences leads to 100 points and a subset of the available competence leads to the respective proportion (score = (number of available competences / number of all competences) * 100). There was no time limit, so all students had the chance to use the system until they achieved as many points as they wanted.

In the first evaluation round (n=28), 27 students achieved 100 points; one only 62 points. In the second evaluation round (n=22), 20 students achieved 100 points, one achieved 92 points, and one dropped out after a few minutes of using the system. The positive learning result is an indicator that the students were highly engaged in using the system and did not get frustrated (except one or two). This result also positively answers the third evaluation question (E3) about whether the learning approach is suitable to learning effectively and to acquiring domain knowledge.

Navigational behaviour: The user interface consists of four main tools (i.e., goal-setting tool, learning tool, assessing tool, and reflection tool) related to different phases of self-regulated learning (see Figure 8.1). In principle, students could freely decide which tools they used, how often, and in which sequence. They had to complete all assessment items provided by the assessment tool and therefore had to select all competences at least once. Analysis of the navigational log data revealed that students had a strong tendency to follow the learning cycle "planning–learning–assessment–reflecting." A second smaller cycle "learning–assessing" could be observed, which is not surprising since it constitutes a more direct way of achieving the required learning score and is a common learning practice in the Austrian educational system. An overview of the navigational behaviour is depicted in Figure 8.1. This diagram shows the relative frequencies of the transitions from one phase to another. For example, the transitions from the planning phase to the learning phase are 0.85 (or 85%) of all transitions from the planning phase. The sum of the relative frequencies from one phase to the other is always 1 (or 100%). Additionally, the diagram shows how often the single tools were used by indicating the relative frequency of the overall number of visits to the tool. When looking at these relative frequencies in more detail, it becomes clear that the learning and assessment phases were visited more often than the planning and reflection phase. Data from both evaluation rounds are presented together and separately in brackets.

These results also answer the second evaluation question (E2): do learners follow the proposed learning approach and do they adopt the self-regulated way of learning? The navigational data shows that learners used all the tools, including those related to metacognition (planning and reflection), without being forced to and that they freely followed the learning cycle, at least to some extent. Main activities shown between the learning and assessment phase might be explained by the fact that students are familiar with this kind of learning, as it is common in the educational context. Interestingly, when additionally using the planning and/or reflecting functionality for their learning, students follow the SRL cycle, meaning that they first plan, then learn, then assess, and finally reflect on their learning before starting again with planning. This behaviour indicates that students adopted the self-regulated way of learning by following the proposed learning approach.

Results of questionnaires

Usability: The system's usability scored well, with an overall average score of M = 76.01 (SD

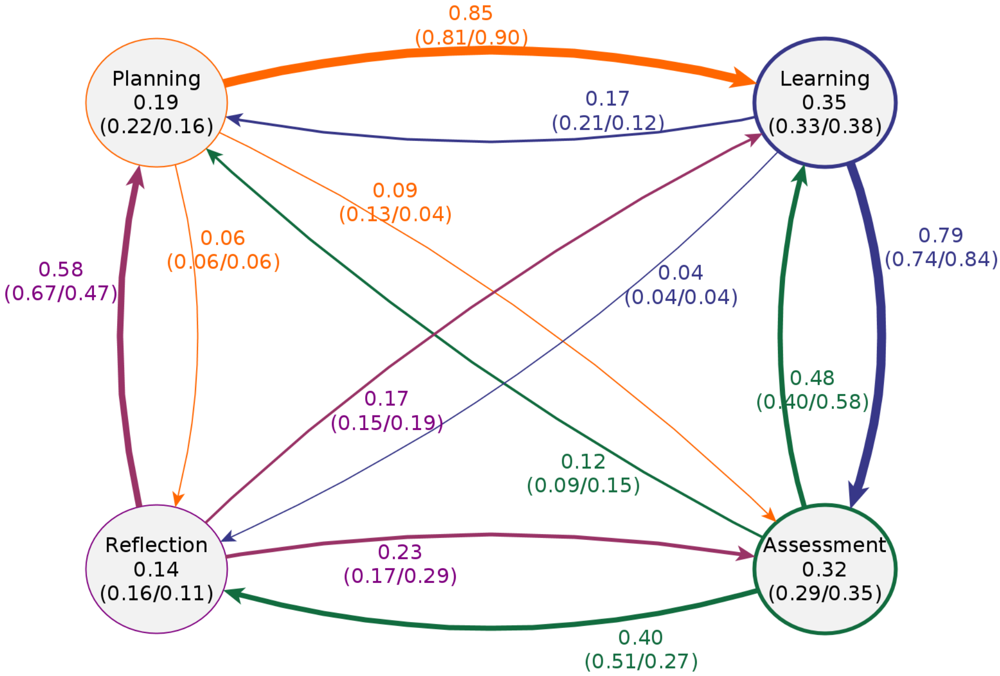


Figure 8.1: Overview of the navigational behaviour between the SRL tools. The arrows indicate navigation from one SRL tool to another and the values indicate the relative frequencies. The picture is taken from Nussbaumer, Hillemann, et al. (2015).

= 12.85, Mdn = 75.00) on a scale ranging from 0 to 100, where higher values indicate a better result. In the first evaluation round, a mean usability score of 79.30 (SD = 12.63; Mdn = 80.00) resulted, which indicated a good to excellent usability of the Compod environment. In the second evaluation round, a slightly lower score resulted with 72.89 (SD = 12.59; Mdn = 72.50). Results are presented in Figure 8.2. Looking at individual items, participants assessed the learnability of the system's functionalities as appropriate, meaning that participants need no additional support in order to work effectively in and with this environment. The lowest result was for the potential future use of the system; however, the resulting score is slightly above the mid-point (M = 2.08; SD = 1.30; Mdn = 2.00), arguing for a satisfactory assessment. This result is also reflected in the qualitative feedback given by participants, where most students appreciated the system's usefulness for learning. Despite some minor spelling errors, they mostly found the system very usable.

User Acceptance: For assessing user acceptance, ratings on the subscales perceived ease of use, perceived usefulness, and intention to use were collected. The results of the mean scores for each individual aspect, as well as the overall score for both evaluation phases, are depicted in Figure 8.3. The best result was for perceived ease of use, with M = 6.33 (SD = 0.84, Mdn = 7.00) in the first evaluation round and M = 5.58 (SD = 1.50; Mdn = 6.00) in the second. Students found the system generally easy to use. The overall score for ease of use, taking into account both evaluation rounds (M = 5.95; SD = 1.27; Mdn = 6.00), was strongly correlated with usability: r = 0.65 (p = 0.00). This means that students who gave the system high marks for usability also gave it high marks for ease of use. For perceived usefulness (M = 4.57; SD = 2.03; Mdn = 5.00)

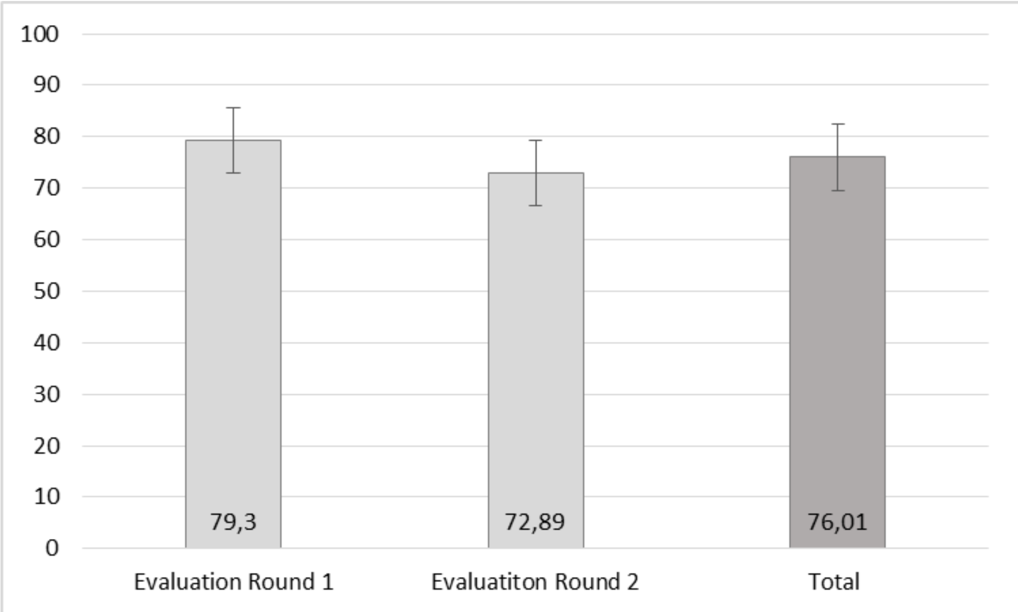


Figure 8.2: Overview of results (mean scores and SDs) on the aspect usability for both evaluation rounds and total usability score. The picture is taken from Nussbaumer, Hillemann, et al. (2015).

and intention to use (M = 4.35; SD = 2.09; Mdn = 4.50), slightly lower values could be identified. Perceived usefulness was rated at M = 4.89 (SD = 2.00; Mdn = 5.5) in the first evaluation round and M = 4.26 (SD = 2.08; Mdn = 5.00) in the second. Intention to use resulted in a mean score of 4.69 (SD = 2.09; Mdn = 5.25) in the first and 4.03 (SD = 2.10; Mdn = 4.00) in the second. Overall, this indicates a medium to good result and is completely in line with the qualitative feedback given by participants, who highlighted the support for learning that the system can provide.

Learning Approach and System Guidance: In the third questionnaire, students were asked to assess the overall learning approach and the guidance facilities provided by the system. Overall, the learning approach was rated as moderately good, with a mean score of 5.35 (SD = 1.30; Mdn = 5.67) on a scale ranging from 1 to 7 where higher values meant a better result. In the single evaluation rounds, a mean score of 5.65 (SD = 1.19; Mdn = 5.67) was obtained in the first round and 5.03 (SD = 1.35; Mdn = 5.33) in the second. Looking at the items for both evaluation phases, it became obvious that students found the learning approach not only supportive for learning generally, but also provided them with a better learning experience than other learning systems. The detailed results of the individual items are displayed in Figure 8.4. These generally positive results were also confirmed by the students when explicitly asked about the strengths and weaknesses of the system and its underlying approach. Most of them liked the cyclical learning approach, especially the feedback function because it provided a good overview of which questions had not been answered correctly. However, they also remarked critically that it was not clear at the beginning how to work through these different learning cycles (i.e., planning, learning, assessing, and reflecting) and how to use the different functionalities provided by the system, especially the visualisations (i.e., clicking on bubbles and marking them with different colours). With this in mind, a small tutorial would facilitate dealing with the environment.

Similar results were obtained when assessing the guidance functionality provided by the sys-

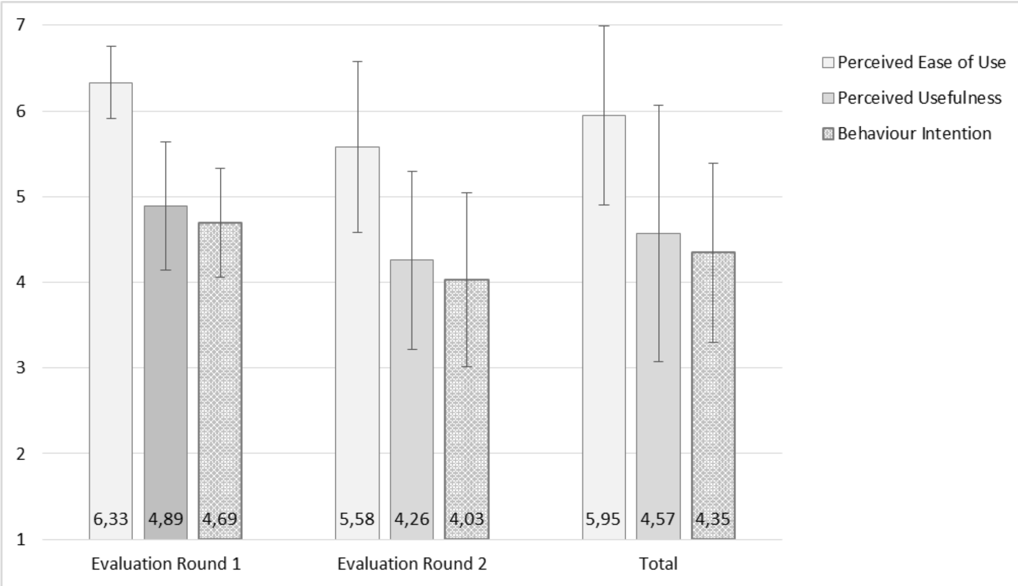


Figure 8.3: Overview of results (mean scores and SDs) on the user acceptance aspects: perceived ease of use, perceived usefulness, and intention to use for both evaluation rounds and in total. The picture is taken from Nussbaumer, Hillemann, et al. (2015).

tem. In the first evaluation, this aspect was rated at M = 5.56 (SD = 1.12; Mdn = 5.67) and the second at M = 5.25 (SD = 1.57; Mdn = 5.67). This resulted in an overall score of M = 5.41 (SD = 1.35; Mdn = 5.67) as depicted in Figure 8.5. These positive results indicate that participants see the additional support this guidance functionality provides to their learning. They also highlighted the freedom to plan and organise learning on their own. However, they also pointed out that a primer on how to use and apply the learning approach and guidance functionality would be helpful.

Goal-Setting Tool: Concerning the goal-setting tool, good to medium results were obtained for both usability and benefit. For usability, a mean value of M = 5.35 (SD = 0.84; Mdn = 5.60) in the first evaluation round and M = 4.79 (SD = 1.12; Mdn = 4.80) in the second were found. Benefit was rated slightly lower with M = 4.36 (SD = 1.12; Mdn = 4.29) in the first evaluation and M = 4.43 (SD = 0.88; Mdn = 4.29) in the second. When looking at the single subscales, in the first evaluation round scores ranged from 4.00 (SD = 1.08; Mdn = 4.00) in the cognitive load scale to 5.47 (SD = 1.05; Mdn = 5.50) in the self-descriptiveness scale. In the second evaluation round, similar results were obtained, with mean scores ranging from 3.79 (SD = 0.90; Mdn = 3.50) in the cognitive load scale to 4.79 (SD = 1.17; Mdn =4.50) in the suitability scale. Table 8.2 shows all results in detail.

Reflection tool: Similarly to the goal-setting tool, this type of visualisation also received good results in all aspects (see Table 8.3). In the first evaluation round, the scores ranged from 4.03 (SD = 0.87; Mdn = 5.50) for cognitive load to 5.41 (SD = 1.19; Mdn = 5.00) for self-descriptiveness, resulting in an overall usability score of 5.25 (SD = 1.22; Mdn = 5.50) and an overall benefit score of 4.19 (SD = 1.21; Mdn= 4.57). In the second evaluation round, similar results were identified: scores ranged from 3.86 (SD = 0.92; Mdn = 3.50) for cognitive load to 4.92 (SD = 1.48; Mdn = 4.50) for suitability for the task. The overall usability score was M = 4.82 (SD = 1.33; Mdn =

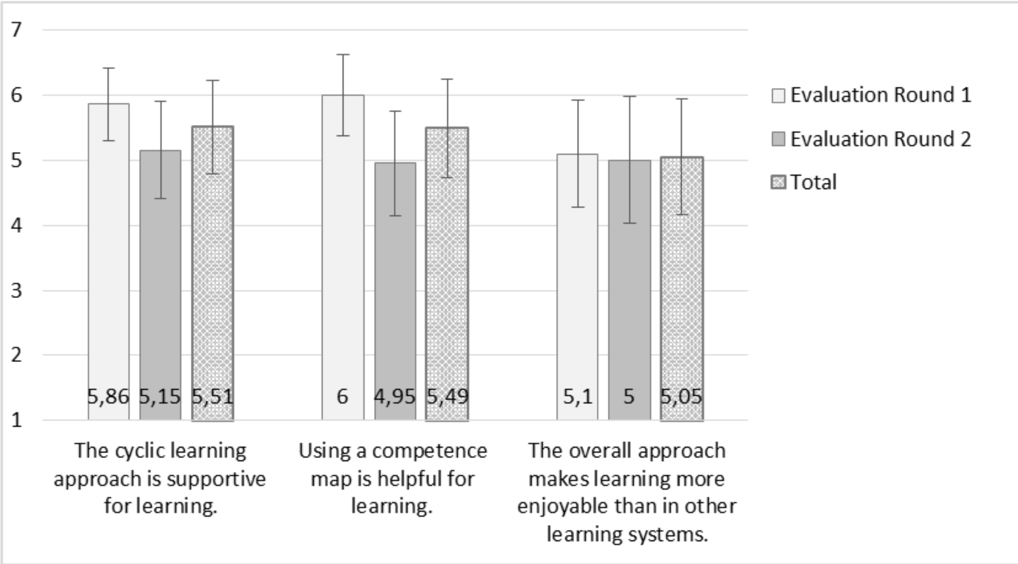


Figure 8.4: Results on items assessing the learning approach used by the system. The picture is taken from Nussbaumer, Hillemann, et al. (2015).

Table 8.2: Results of the subscales, total usability, and total benefit for the goal-setting tool.

	Evaluation Round 1	Evaluation Round 2	Total
	Mean (SD)	Mean (SD)	Mean (SD)
Suitability for the task	5.03 (1.18)	4.79 (1.17)	4.91 (1.17)
Self-descriptiveness	5.47 (1.05)	4.63 (1.34)	5.05 (1.26)
Total Usability	5.35 (0.84)	4.79 (1.12)	5.07 (1.02)
Metacognition	4.61 (1.42)	4.77 (1.08)	4.69 (1.12)
Cognitive Load	4.00 (1.08)	3.79 (0.90)	3.89 (0.99)
Learning-effectiveness	4.26 (1.42)	4.21 (1.22)	4.24 (1.30)
Total Benefit	4.36 (1.12)	4.43 (0.88)	4.39 (0.99)

4.50) and the benefit score was M = 4.51 (SD = 1.05; Mdn = 4.43), also satisfactorily good results. These results indicate that students find the tool suitable for reflecting on their learning and see the benefit it can provide.

Summing up the results obtained for both types of visualisations used by the Compod system, generally students agreed that visualisations provide useful and relevant information in terms of better planning and reflecting on their learning. These results were confirmed in the qualitative feedback. Most participants found that the goal-setting visualisation provides useful information and is thus suitable for planning future learning activities, especially the opportunity to see the dependencies between topics (i.e., main topic and sub-topic). Additionally, students appreciated being able to organise their own learning process by simply choosing and clicking on their own learning goals. On the other hand, however, they pointed out the complexity of the visualisation type (i.e., the Hasse Diagram) and consequently the need for a short tutorial (e.g., video or animation) explaining the functions (e.g., choosing a bubble, which consequently changes his colour). Regarding the reflection tool, participants found it clear, easy to understand, and that it provided good and useful information.

On a nominal level, the Compod system and services were assessed slightly higher in most

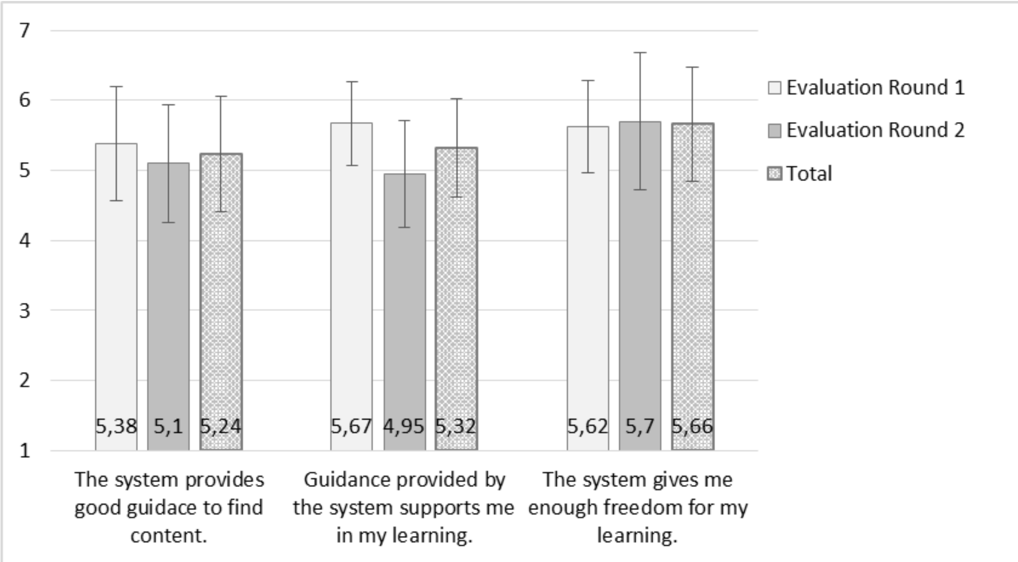


Figure 8.5: Results on items assessing the guidance functionality provided by the system. The picture is taken from Nussbaumer, Hillemann, et al. (2015).

Table 8.3: Results of the subscales, total usability, and total benefit for the reflection tool.

	Evaluation Round 1	Evaluation Round 2	Total
	Mean (SD)	Mean (SD)	Mean (SD)
Suitability for the task	5.09 (1.51)	4.92 (1.48)	5.00 (1.48)
Self-descriptiveness	5.41 (1.19)	4.72 (1.34)	5.06 (1.30)
Total Usability	5.25 (1.22)	4.82 (1.33)	5.03 (1.28)
Metacognition	4.41 (1.50)	4.80 (1.35)	4.61 (1.42)
Cognitive Load	4.03 (0.87)	3.86 (0.92)	3.94 (0.89)
Learning-effectiveness	4.29 (1.51)	4.39 (1.40)	4.34 (1.43)
Total Benefit	4.19 (1.21)	4.51 (1.05)	4.36 (1.13)

qualities in the first evaluation study than in the second. The two exceptions were the goal-setting tool and the reflection tool, which were rated lower in the first study. However, statistical comparisons within the sample (t-tests for independent samples or, respectively, non-parametric tests where necessary) between the evaluations of the two student cohorts yielded no significant differences.

8.1.3 Discussion

Referring to our original research questions, the main aim was to create a framework composed of different learning methodologies and system implementing this framework that supports learners to follow the self-regulated learning paradigm and to acquire knowledge of the subject domain. The proposed solution to these research questions was described in our psycho-pedagogical framework that incorporates Competence-based Knowledge Space Theory, personalisation approaches, the Open Learner Model, and learning analytics methods, in order to provide personalised guidance in a self-regulated learning process. In order to validate the proposed solutions, a study, guided by four evaluation questions was undertaken to give insight into the extent to which this framework and system answer the research questions. In this evaluation, a descriptive study design using a multi-method approach for gathering data was used in order to gain in-depth data on the usefulness and applicability of the Compod system and its different functionalities. To ensure the same learning conditions for each learner in the context of a university course where students finished with a certificate, no control group was established. Because of the chosen design, the study also did not include a pre-test–post-test condition. This might be problematic, especially when making conclusions about the learning effectiveness of the system. However, the focus of this formative evaluation, as well as discerning what was good and useful to students, was on identifying any issues or potential problems with the technology and the underlying learning approach from a user-centred perspective. Such a procedure should ensure that valuable information for further improvement of the software is provided to the developer.

The first evaluation question (E1) addresses the usability and user acceptance of the overall system and approach. The results from questionnaires were rather good on both user acceptance and usability. This indicates that, in general, the system and its approach are acceptable. The second evaluation question (E2) specifically targets the learning approach and thus the framework. The results from these questionnaires indicated that students like this way of learning. The third evaluation question (E3) asked if learners actually acquire domain knowledge with this learning approach. Results retrieved from the user-model data show that learners achieved the goal of mastering the subject domain. Almost all students achieved the maximum score even though this was not required. Finally, the forth evaluation question (E4) specifically targets the goal setting and reflection tools and their visualisations. Results indicate that usability and the benefit for the learning process is above average, and students explicitly pointed out the positive effects in the qualitative feedback.

Overall, the results of the study are quite promising, indicating that the elaborated framework and developed system fulfil their purpose. Individual results on the evaluation questions point out that students accepted the system with its functions, user interface, and pedagogical framework. Additionally, the learning results in terms of domain knowledge were successful. If the system and the framework are suitable for self-regulated learning and achieving the learning goals, then the Compod system passed this test.

8.2 External VLE

While the evaluation presented in the last section focused on the Compod VLE, there where also other evaluations conducted in the context of external VLEs as presented in Chapter 7. One of these evaluations is scientifically published, the others are reported in non-public deliverables of research projects.

The evaluation of the INNOVRET approach is reported by Dimache et al. (2015); Kopeinik et al. (2014). The context of this evaluation is described in Section 7.5. A Moodle extension was created that facilitates self-regulated learning by using the Compod service in the background for learning path recommendation, assessment procedures, monitoring, and goal setting, and management of the domain and user model. The work on the Moodle extension and the planning and conducting of the evaluation was conducted by colleagues involved in the INNOVRET project.

This evaluation included two groups, a control group using Moodle without SRL and Compod (N=8), and a experimental group using the SRL approach with Compod service (N=6). The learning content included material about heat pumps, their installation and maintenance. During the experiment the participants (both groups) used Moodle, in order to learn the available content. After the learning session, they had to fill out a questionnaire with 10 items. The items are listed in Table 8.4. Then they had a personal interview with the researchers.

Table 8.4: This table lists the items of the questionnaire. The items marked with "–" are negatively posed questions.

Q1	The cycle of learning, assessment, and visualisation was good for my learning
Q2	The system supported me to become aware about my learning process
Q3–	The system was limiting my learning
Q4	The system provided helpful guidance for my learning
Q5–	This way of learning was stressful
Q6	I enjoyed the way of learning with that system
Q7	I was successful with the learning task
Q8	The information in the user interface was easy to understand
Q9	I would like to use ta system like this in the future
Q10	I am happy with the quality of the content presentation

The results from the questionnaires are depicted in Figure 8.6. The experimental group were slightly above average in all questions and slightly more positive than the control group. Three of the questions targeting the overall approach, namely the iterative learning process (Q1), the awareness support (Q2), and the guidance support (Q4), were answered above average. Two negatively posed questions concerned learning problems, namely: if this approach was limiting (Q3) or stressful (Q5). According to the answers the CbKST approach is less limiting. Further questions targeted the participants' enjoyment (Q6) and the perceived learning success (Q7), which were both above average and better than for the control group. The user interface (Q8) and the content quality (Q10) were above average and similar to the control group. The question, if the users would like to use a system like this in the future (Q9) resulted clearly above average and was considerably better than for the control group.

In the interviews after the learning task, the participants with good IT skills felt positive regarding the CbKST approach. However, other people with poor IT skills had problems with the system in principle, which might have had a negative influence on the questionnaire results. This is also visible in the rather high standard deviation values between 0.98 and 1.47 for the ten questions (see Figure 8.7). All participants found that there is room for improvement regarding the simplicity of the user interface.

According to the log data of the CbKST group the participants, on average have performed 3.2 learning iterations, visited 9.4 learning objects, followed 82% of the recommended learning objects, and answered 9.2 assessment questions.

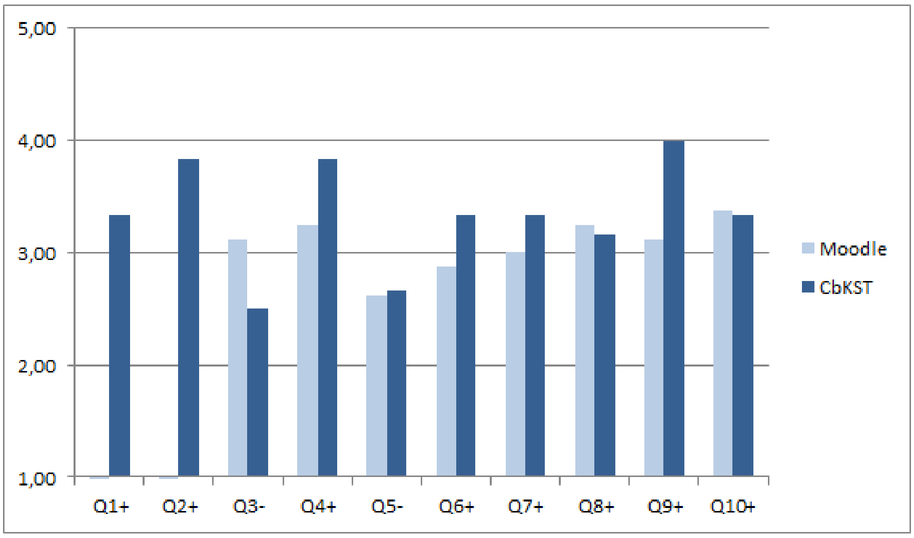


Figure 8.6: This figure show the results of experimental and control group regarding the questionnaire in the INNOVRET evaluation. This picture is also published in Kopeinik et al. (2014).

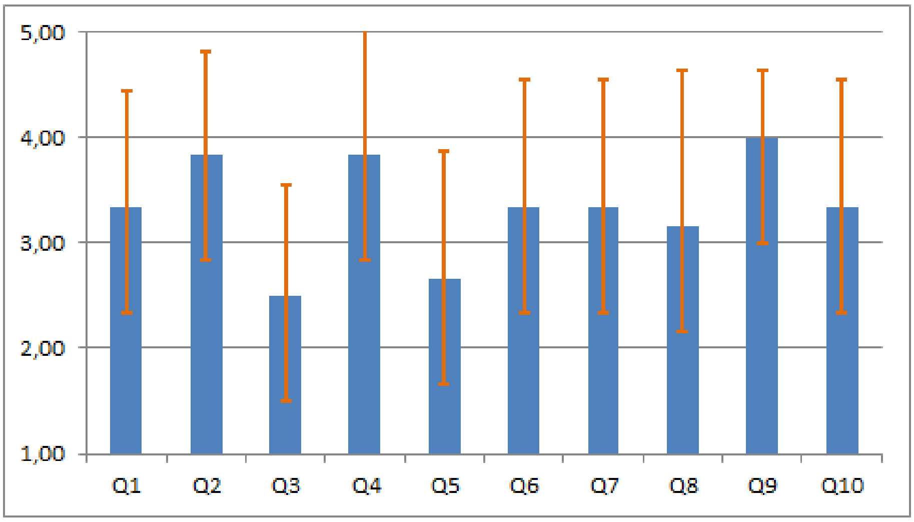


Figure 8.7: This figure shows the results including standard deviation of the experimental group regarding the the questionnaire in the INNOVRET evaluating.

8.3 Discussion

The presented evaluation in this chapter investigates the Compod approach from two perspective. On the one hand, the Compod VLE has been used for evaluating, which is created in order to implement the conceptual framework with many of its features. On the other hand, Moodle with an extension for SRL was used, that used only a subset of the framework features. While the first setting rather represents the “pure” approach, the second one represents a realistic one.

Overall the evaluation results of the Compod VLE and the external VLE are satisfying. The participants liked the learning approach and would use it again. Both evaluations included data from questionnaires and log data. While the questionnaires aimed at asking the participants regarding the opinion, the log data contain information how the system including Compod was actually used. Both aspects were quite positive. In the questionnaires the participants responded with positive attitude regarding the overall all approach and its aspects. The log data indicated that the participants followed the recommendations and accepted the SRL way of learning. The learning effectiveness could be observed by the attainment of competences.

A critical point could be observed in an unpublished evaluation of the iClass approach with school pupils. In this evaluation problems with the understanding of the overall concept of competence structures appeared. This observation is similar to the INNOVRET evaluation, where participants with low IT skills had problems with the overall approach. This clearly indicates that the overall approach requires a good understanding of information presented in form of CbKST structures. Obviously this was not a problem in the evaluation study with master students in computer science, which is not surprise.

This observation emphasises the importance of having the target users in mind, when creating and using a VLE with this learning approach. It is one of the main features of Compod to be used in different types of VLEs. This provides the opportunity to use VLEs with simplified user interfaces for young learners or learners with special needs, and complex interfaces for skilled learners. The INNOVRET approach used a simplified version of the goal setting, as this was more suitable for their target users. Thus this also demonstrates the flexible approach of the conceptual framework and Compod.

Chapter 9

Lessons Learned

This section gives subjective insights in the experiences gained during the work on this doctoral thesis. This includes both aspects barriers and problems made during the work and insights towards future scientific work.

The thesis makes several **contributions to Technology-enhanced Learning (TEL) research**. The most important ones are Learning Analytics (LA), Open Learner Model (OLM), User Model (UM), Adapation and Personalisation, and Self-regulated Learning (SRL). The imact is shortly described in the following paragraphs.

Learning analytics is addressed by using monitoring data of learning behaviour for recommendation and feedback. While learning analytics often just provides nicely presented statistics of data from learner behaviour, the approach of this thesis, uses cognitive models based on Competence-based Knowledge Space Theory (CbKST) for translating behavioural data into meaningful feedback and recommendation.

Another addressed field research on ***Open Learner Models (OLMs)***. OLMs are used for opening up information used by adaptive systems to the user, in order to make the adaptation process understandable and to impact on metacognition. In this work user and domain models based on CbKST are depicted graphically, in order to provide an understanding of the learning content, goals, and progress. Furthermore, they where used to allow interaction of the user with these models, for example, by goal setting techniques.

User models are a prominent research field in the context of adaptive systems. This thesis contributed to this field, by defining a user model based on CbKST. This user model consists of two parts, the cognitive state and the behavioural history. A connection is made by calculating cognitive state information (e.g. available competences) through algorithms (e.g. competences assessment). Furthermore, learners are provide access to their user models, in order to get insights and manipulate them.

Adaptation and personalisation has a long tradition in TEL. This thesis provides an approach for personalising the learning experience based on CbKST and SRL. By taking into account, the user model with all its aspects, personalisation is provided through recommendation and feedback.

The impact on ***self-regulated learning*** was made by elaborating a technical approach for supporting this kind of learning. SRL has a long tradition as theoretical field in pedagogy and psychology, but little technical solutions have been created, to effectively support it. This thesis provides an approach, to support SRL through appropriate learning tools for performing metacognitive activities.

The results from the evaluation indicate a potential **impact on the educational sector**. An overall applicability could be observed, since it turned out that the participants accepted and liked the overall approach and the the approach could successfully applied in different VLEs. However, it would take further efforts, to achieve a maturity level of the software that allows the deployment in educational organisations.

During the work on this thesis it turned out that the **clarification of the names and meaning** of all the concepts and constructs are of an essential importance. This work is embedded in a huge and multi-disciplinary research area. This area includes different research fields (e.g. computer science, pedagogy, and psychology) and different application areas (e.g. educational organisations, technology providers, and funding organisations). Thus, people from many different areas with different background and working experience are involved in TEL.

Considering this situation, it is not surprising, that terms and concepts are used differently and ambiguously, often without clear meaning or in an overlapping way. When examining literature on TEL, existing TEL software, or case studies, the incoherent use of terms are often misleading, which leads to a fuzzy understanding, often in an unconscious way. For example, the terms Learning Management System and Virtual Learning Environment are constantly used with different meaning. In this specific case, the reaction to it was the clear definition of these terms in Chapter 3. However, in total many other terms could not be clearly defined during this work, due to a lack of time, or to little sensibility while focusing on topics closer related to the research.

Another issue experienced from this work is the **scope of research**. The thesis included two main research topics. First, the elaboration of a conceptual framework that takes into account different learning concepts from pedagogy, psychology, and computer science, with the goal of integrating them to a new learning approach. Second, the integration of this conceputal framework in different VLEs with their own learning approaches. Though this combination is meaningful and both parts support each other, it constitutes a big research areas for a doctoral thesis.

Such a big research field resulted in research that misses some degree of profoundness. There are several aspects in this work that could have been researched in a more concise way. For example, the elaboration of the conceptual framework would benefit from a more formal description with better definition of all the included constructs and their relations to each other. Furthermore, components and aspects of this framework could be evaluated individually, in order to proof or improve each part of it. On the other hand, the integration of the framework with VLEs could be specified and evaluated in more detail and all its aspects.

On the other hand this broad research areas also has its opportunities. By elaborating the conceptual framework and its integration in difference learning contexts, new possibilities for further detailed research are provided. Both areas could serve as topic and scope for further research endeavours.

The magnitude of the research area is also represented in the available **literature on TEL**. According to the interdisciplinary field of TEL, also the scientific literature has a strong interdisciplinary character targeting computer science, psychology of learning, and pedagogy. Additionally, lots of literature can be found that targets practitioners in the educational sector. When doing literature survey, it is easy to get lost in many interesting aspects and reports that do not clearly related to the topic of the thesis. This leads the difficulty of omitting and ignoring interesting information, but still focusing on essential aspects.

Following the focus on selected types of VLEs (Chapter 3) and selected learning concepts in TEL (Chapter 4), the selection of relevant literature could be restricted. The second approach to focus on essential literature was a view on these topics from a historical perspective by tracing the evolution of these concepts.

This thesis followed a **application-driven research motivation**. There are different methodologies how research can be motivated. For example, research opportunities and needs can be identified from literature review or research can target empirical experiments for gaining new knowledge. The research of this thesis was motivated by an analysis of existing VLEs, their advantages, characteristics, and downsides. From this analysis, it became clear what each of them is missing and how they would benefit from additional features.

This analysis resulted in the definition of the conceptual framework that is supposed to bring in the missing features to VLEs in a flexible way. On the other hand, the conceptual framework was grounded on existing learning concept, in order to have a strong theoretical background of the framework.

This methodology has the advantage that the research had a clear goal towards a realistic application scenario with an understanding who can benefit from the results in which way. Still a missing point in this approach are systematic studies that scientifically justify the missing features of the VLEs.

However, there was also an effect on the **software development** coming from the application-driven approach. Instead of doing the software development after conceptual work, the development and framework constantly evolved over the time. Each time, a new application case was targeted, both the conceptual framework and the software development changed. To some extent this resulted in a co-evolution of framework design and software development. The downside of this method is a fragmented software which features that are not used anymore.

Chapter 10

Conclusion and Outlook

10.1 Conclusion

This doctoral thesis presents a conceptual framework and software application that aims at enriching existing learning technology with an approach for personalised, competence-based, and self-regulated learning. Overall, it consists for two main parts. First, a conceptual framework has been developed that describes a learning approach based Adaptive Educational Hypermedia (AEH), Self-regulated Learning (SRL), and Competence-based Knowledge Space Theory (CbKST). This learning approach supports personalised, competence-oriented, and self-regulated learning in a coherent way. Second, a technical framework has been created consisting of a technical design and a software that implements learning support based on the conceptual framework.

The conceptual framework is based on the key concepts of AEH, SRL, and CbKST. By using key features of each of them, a coherent approach for learning has been created. This approach is characterised by a balancing the control of the learning process, provide support for acquiring knowledge and competences in a subject domain, and for empowering self-regulated learning and the attainment or related meta-cognitive competences. The approach is not fixed to specific form or learning guidance, but it can be employed in a flexible way. For example a focus on the adaptation features leads to a reduction of self-regulated learning. Vice versa, a focus on self-regulation leads to a reduction of adaptation, but guidance can still be realised through recommendations and feedback.

Four techniques have been elaborated that support the learning approach defined in the conceptual framework. Assessment based on CbKST procedures facilitates efficient and adaptive competence assessment. Monitoring tracks the activities of a learner in a systematic way, so that the attained information can be used for further actions. Recommendation provides active guidance by proposing learning content and meta-cognitive activities. Feedback provides information of the learning history in terms of performed actions and cognitive states (acquired competences of goal competences).

Furthermore, a knowledge representation model forms the basis for the learning support. Subject domains are represented in domain models that include information on competences, learning content, and assessment items. This information is structured following the CbKST approach. A user model is defined as an overlay model with referring elements to the domain model. It consists of two parts, first the cognitive states (e.g. attained competences, goal competences, use of meta-cognitive SRL activities), and second, the behavioural actions (e.g. learning content, performed assessment items, used tools). Information on the cognitive states are either calculated by algorithms (e.g. competence assessment) or directly provided by the learner (e.g. goal setting).

The technical framework provides software components to realise the conceptual framework and related learning approach in a practical way. It contains a Web service, and provides access to the knowledge representation model (domain model and user model) and the learning support techniques. Through a set of REST interfaces, this information and functionalities can be used in flexible way. Thus a the learning approach can be used in different forms with varying degree of guidance, adaptation, and self-regulation. This service software is called Compod, which is an abbreviation of "competence pod". In addition to the Compod service, an authoring tool for creating domain models, and an analytics tools for inspecting the learning progress and behaviour of groups have been created.

A key part of the overall approach of this thesis is the integration of the learning approach and technical framework into external Virtual Learning Environments (VLEs). The integration of the Compod service has been tried out with four different types of VLEs, namely Intelligent Tutoring System (ITS), Learning Management System (LMS), Personal Learning Environment (PLE), and Virtual Reality Learning Environment (VRLE). Each of them has its own characteristics and pedagogical approach, which makes them completely different. For example, while ITSs typically offer strict guidance in terms of learning paths, great amount of individual freedom is provides in PLEs and VRLEs. While, LMSs are focused on delivering learning content in a one-size-fits-all manner, ITSs have techniques to personalise the knowledge and competence development of learners. This situation puts a challenge of providing a learning approach and software service that is flexible enough to provide the learning approach in different ways fitting to the individual. This flexibility could be demonstrated in five settings with these LMS.

In an evaluation, the learning approach has been tested with a reference implementation of an external VLE. This reference implementation is called Compod VLE. It provides four learning tools the meta-cognitive SRL activities, goal setting, planning, self-monitoring, self-evaluation, and self-reflection. Furthermore, it makes use of the domain and user model, as well as of the learning support techniques provided by the Compod service. The evaluation consisted in an online course of a university lesson on Information Search and Retrieval. Around 30 students used the course for learning a specific topic of this course in about two hours time. The results of the evaluation suggested the achievement of the aims expressed above. The students could master the topics and responded with a positive attitude regarding the overall learning approach, the individual features of the tools, and the usability.

10.2 Research Results and Contribution

In Section 1.2 four research question are defined that have guides the work on this thesis. This section explains how they were addressed.

RQ 1: How can the three learning concepts Adaptive Educational Hypermedia (AEH), Self-regulated Learning (SRL), and Competence-based Knowledge Space Theory (CbKST) be integrated on a conceptual level in a common framework?

The integration of the three learning concepts are described in Chapter 5. In this chapter an analysis is made of their indiviudal characteristics. Based on this analysis, requirements for an integrated learning approach are derived (see Table 5.1). These requirements include the use of domain and user model structured according to the CbKST approach, the use of methods for creating learning path and providing feedback, the support of meta-cognitive SRL activities and related tools, and a balance between strict adaptation and freedom of learning control. Since, it turned out that the indiviudal characteristics are not mutually exclusive, the could be integrated to a combined framework.

Based on this analysis and requirements, a conceptual framework has been defined that puts together the indiviudal features (see Figure 5.1). This framework consist of three layers, which are a knowledge representation layer, a personalised learning support layer, and a SRL process model layer. In this way this framework has a modular design, which is the basis for the flexible use in different learning environments.

The conceptual framework and evolving versions of it have been published in several scientific conference and journal publications. The most recent version of it is published in (Nussbaumer, Hillemann, et al., 2015). Previous versions are available in (Nussbaumer, Gütl, & Albert, 2007; Steiner et al., 2009).

RQ 2: How can the conceptual framework be translated into a technical framework and system, so that it provides personalised learning support for knowledge acquisition, competence development, and self-regulated learning?

A technical framework and system that implements the conceptual framework is described in Chapter 6. The core part of the technical framework are data and information models (Section 6.2) that are needed to technically represent the knowledge representation model. Furthermore, technical components are presented that implement the personalised learning support techniques of the conceptual framework. Through the conceptual framework, these components are grounded in the theoretical background of AEH, SRL, and CbKST. Thus they are able to provide support for knowledge acquisition, competence development, and self-regulated learning.

On a system level, these learning support components are integrated in a Web service (Compod service) that provides REST interfaces to access these components. Furthermore, the service manages the data models and makes them available for the support components. Together with an authoring tool, a course analytics tool, and a reference implementation of an VLE, a system approach is achieved.

The Compod service and previous versions of it have been published in several scientific conference and journal publications. The most recent version of it is published in (Nussbaumer, Hillemann, et al., 2015). Previous versions are available in (Hockemeyer et al., 2009; Nussbaumer, Gütl, & Hockemeyer, 2007).

RQ 3: How can the technical framework be used by existing Virtual Learning Environments (VLEs) in a way that they benefit from the supported learning approach.

The use of the technical framework (Compod service) in combination with external VLEs is described in Chapter 7. The basis for the integration of the Compod service in external VLEs is the flexible and modular approach of both the conceptual and the technical framework. These frameworks are not bound to static learning approach, but allow the flexibility regarding the degree of guidance (adaptation vs. freedom), the use of the learning support techniques and components, and the access on the knowledge representation models.

Compod service has been tried out with four different types of VLEs, namely ITS, LMS, PLE, and VRLE. Each of them has its own characteristics and pedagogical approach, which makes them completely different. Individual applications within these VLEs integrated the learning approach in different ways by taking into account the varying learning environments.

The application of the Compod service and related learning approach have been published in several scientific conference and journal publications, for example (Hockemeyer et al., 2009; Kopeinik et al., 2014; Nussbaumer et al., 2010, 2009).

RQ 4: What is the effect, advantage, and acceptance of the overall approach for learners, teachers, and tutors?

An evaluation of the learning approach in combination with the reference implementation Compod VLE is described in Chapter 8. Compod VLE was suitable for testing the overall learning approach, as it has implemented many of the features available though the technical framework and service. For example, it provides four learning tools the meta-cognitive SRL activities, goal setting, planning, self-monitoring, self-evaluation, and self-reflection. Furthermore, it makes use of the domain and user model, as well as of the learning support techniques provided by the Compod service.

The evaluation consisted in an online course of a university lesson on Information Search and Retrieval. Around 30 students used the course for learning a specific topic of this course in about two hours time. The results of the evaluation suggested the achievement of the aims expressed above. The students could master the topics and responded with a positive attitude regarding the overall learning approach, the individual features of the tools, and the usability.

This evaluation is published a scientific journal publication (Nussbaumer, Hillemann, et al., 2015). A further evaluation in the context of the Moodle application for vocational training is published in (Dimache et al., 2015; Kopeinik et al., 2014).

10.3 Open Issues and Future Work

The work on this thesis has left some topics and issues that are not fully dealt with or are not taken into account at all. This section shortly describes some them.

Role of teachers and tutors. In principle the goal was to elaborate and develop a learner-centric approach. However, as indicated in previous chapters, there is also the perspective of teachers and tutors that should be taken into account. To some extent, this perspective is treated in the course analytics tool where the learning progress and behaviour of individual learners and groups of learners can be observed (see Section 6.5). Despite this tool, there is more room for conceptual work and development that supports the teachers. For example, the creation and management of courses could integrated in the overall approach. Though this is done by some external

VLEs (e.g. LMSs), other VLEs do not know this concept (e.g. SecondLife).

Evaluation. An extensive evaluation was performed with Compod VLE to test the overall approach. In addition, the integration of Compod service with external VLEs can be seen as technical evaluation or proof of concept. However, specific evaluation in terms of learning achievement and acceptance would strengthen the conceptual and technical framework. It would specifically interesting, how the combination of varying pedagogical approaches of the different VLEs provide benefits for the learners, if used with the Compod service. Another aspect of evaluation targets the teacher and tutors. Also their views were not taken into account in this thesis. In combination with conceptual and technical work addressing teacher needs, an evaluation would be meaningful to better understand strengths and weaknesses.

Learning tool repositories. In this thesis, the term learning tool was used with respect to tools for dealing with learning objects, assessment items, planning and goal setting, and reflection. In combination with these tools self-regulated and meta-cognitive activities were taken into account. However, presently, the open repositories for learning tools are a dominant phenomenon, especially in the context of mobile devices. The work in the ROLE project addressed this situation by elaborating ontologies that assign cognitive and meta-cognitive learning activities to those learning tools and by providing personalised recommendations of such learning tools (Nussbaumer, Dahn, et al., 2015; Nussbaumer et al., 2014; Renzel, Klamma, Kravcik, & Nussbaumer, 2015). This approach can be taken up to be integrated with the conceptual framework and implementation.

Visualisations for reflection. The Compod service collects data from leaner behaviour including the use of learning resources and the interactions with them. Currently, this information is used to provide feedback in visual way regarding competence development and use of learning material. However, there is great potential to make deeper analysis of the leaner behaviour and to visualise the resulted data. In experiments the usefulness of more sophisticated information could be tried out. For example, such a visualisation could be inspired from the graphics that depicts the navigation behaviour as depicted in Figure 8.1 (which was created manually). A further type of visualisation could be a comparison with the learning outcomes and behaviour of peers (in a more sophisticated way as shown in the course analytics tools).

Appendix A

Compod Installation Guide

This appendix explains how to install the Compod application. Compod is Web service developed as a Java Servlet. The current version is compiled with Open JDK 7 and tested with Tomcat 7 on Ubuntu 14.04. It needs an SQL database, where MySQL 5.5 has been used for development and the deployed version. All this software is available as the default packages of Ubuntu 14.04.

The Compod installation has to be done semi-automatically. A script is available that tests the installation and reports installation problems. The following files are included in the Compod installation package:

- compod.war - the Compod binary
- createuser.sql - the SQL script that creates the compod database user
- createdb.sql - the SQL script that creates the database structure
- crateappdata.sh - the BASH script that creates a directory in the Tomcat installation directory
- compod.properties - a configuration file that includes database settings and file locations
- check-installation.sh - a BASH script that tests the installation
- installation-guide.txt - a description for the installation (the information of this chapter)

The installation is done in five steps. The installation guide assumes that MySQL user name, password, and database name is "compod". If changed, than this has to be done in the compod.properties file and the step where the database is initialised. Furthermore, the tomcat7 directory has to be identified (usually in /var/lib/tomcat7) – here denoted as <TOMCAT-DIR>.

1) Database configuration

```
# creates 'compod' user with full access to 'compod' database
mysql -u root -p < createuser.sql

# creates 'compod' database structure and demo data
mysql -u compod -p'compod' compod < createdb.sql

# test, if user and tables have been created
mysql -u compod -p'compod' compod -e 'show tables;'
```

2) Configuration File

```
# copies the compod conf. file into Tomcat conf. folder
# change MySQL username, password, and database name if needed
> sudo cp compod.properties <TOMCAT-DIR>/conf/
```

3) Data Directory

```
# creates 'appdata/compod/log' in <TOMCAT-DIR>
# write access for tomcat7 is given on the 'log' directory
> sudo create-appdata.sh

# tests if log dir is available and tomcat7 has write access
> ls -la /var/lib/<TOMCAT-DIR>/appdata/compod/
```

4) Compod binary

```
# copy compod.war to <COMPOD-DIR>/webapps
# Tomcat automatically installs the software
# then wait until the directory 'compood' has been created
cp compod.war <TOMCAT-DIR>/webapps/
```

5) Test installation

```
# tests if the installation is correct
run check-installation.sh

# a further test can be done by accessing the REST interface:
http://localhost:8080/compod/rest/getversion
http://localhost:8080/compod/rest/getdomainmodels
http://localhost:8080/compod/admin/getstatus
```

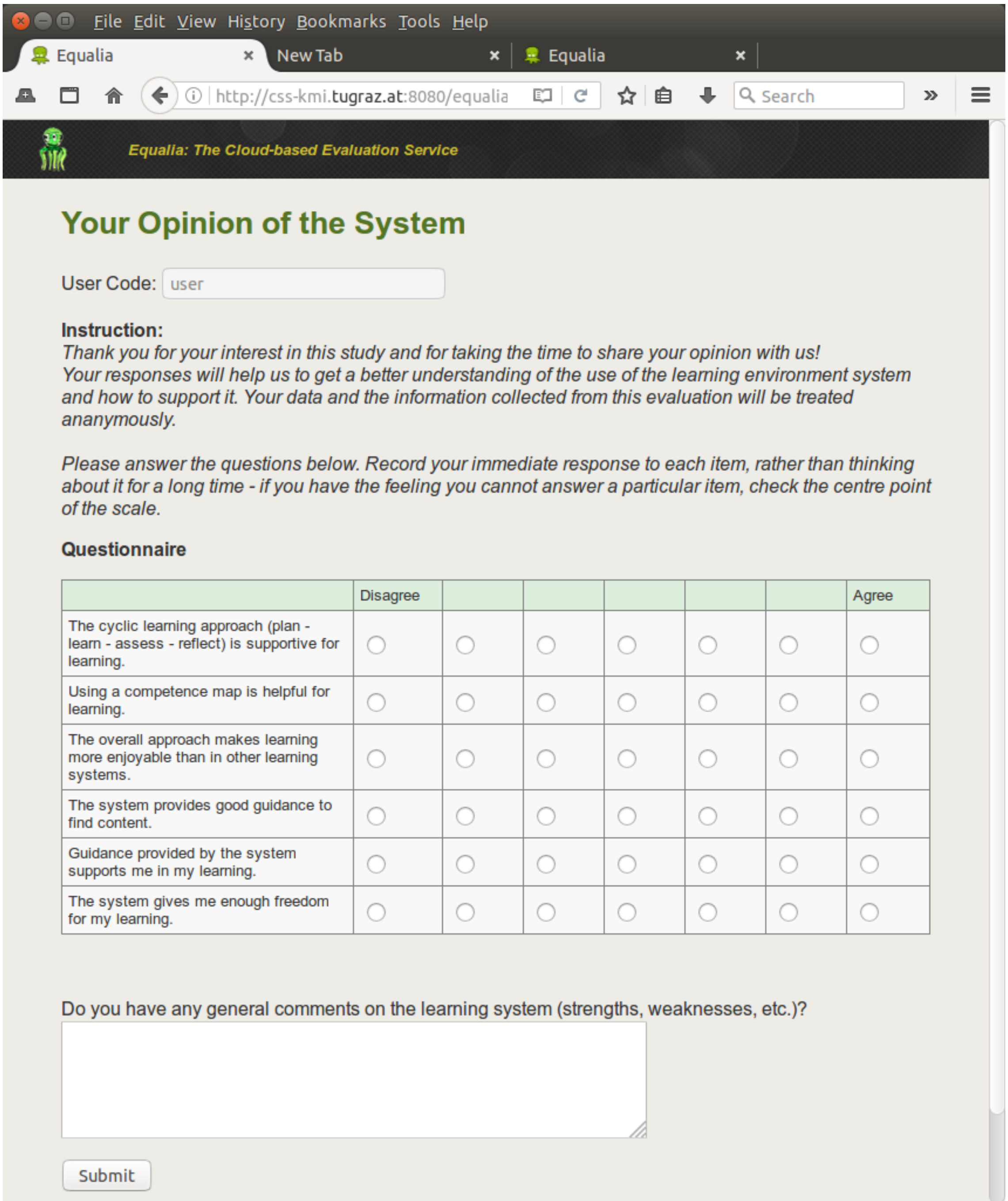
If everything is fine, then the Web interface can be used to try out the administration tool of Compod:

http://localhost:8080/compod/web/

Appendix B

Material Used for Evaluation

This appendix chapter presents the questionnaires used for the evaluation of Compod including learning approach, visualisation tools, and usability. The questionnaires are described in Section 8.1.1. They are depicted in the figures on the following pages (Figure B.1, Figure B.2, Figure B.3, Figure B.4, and Figure B.5).



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http://css-kmi.tugraz.at:8080/equalia Search

Equalia: The Cloud-based Evaluation Service

Your Opinion of the System

User Code: user

Instruction:
Thank you for your interest in this study and for taking the time to share your opinion with us! Your responses will help us to get a better understanding of the use of the learning environment system and how to support it. Your data and the information collected from this evaluation will be treated ananymously.

Please answer the questions below. Record your immediate response to each item, rather than thinking about it for a long time - if you have the feeling you cannot answer a particular item, check the centre point of the scale.

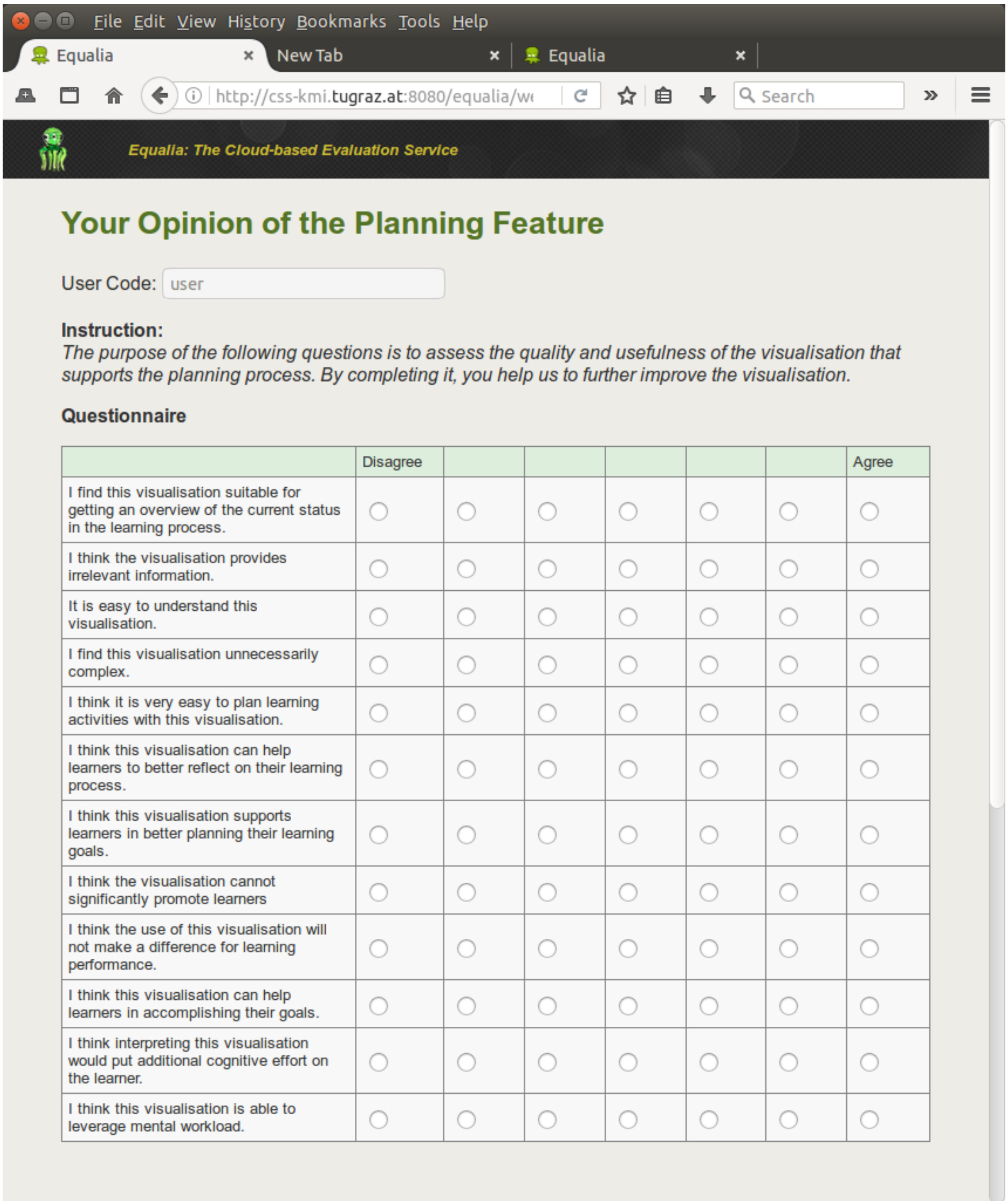
Questionnaire

	Disagree						Agree
The cyclic learning approach (plan - learn - assess - reflect) is supportive for learning.	○	○	○	○	○	○	○
Using a competence map is helpful for learning.	○	○	○	○	○	○	○
The overall approach makes learning more enjoyable than in other learning systems.	○	○	○	○	○	○	○
The system provides good guidance to find content.	○	○	○	○	○	○	○
Guidance provided by the system supports me in my learning.	○	○	○	○	○	○	○
The system gives me enough freedom for my learning.	○	○	○	○	○	○	○

Do you have any general comments on the learning system (strengths, weaknesses, etc.)?

Submit

Figure B.1: Questionnaire: Your Opinion of the System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Equalia: The Cloud-based Evaluation Service

Your Opinion of the Planning Feature

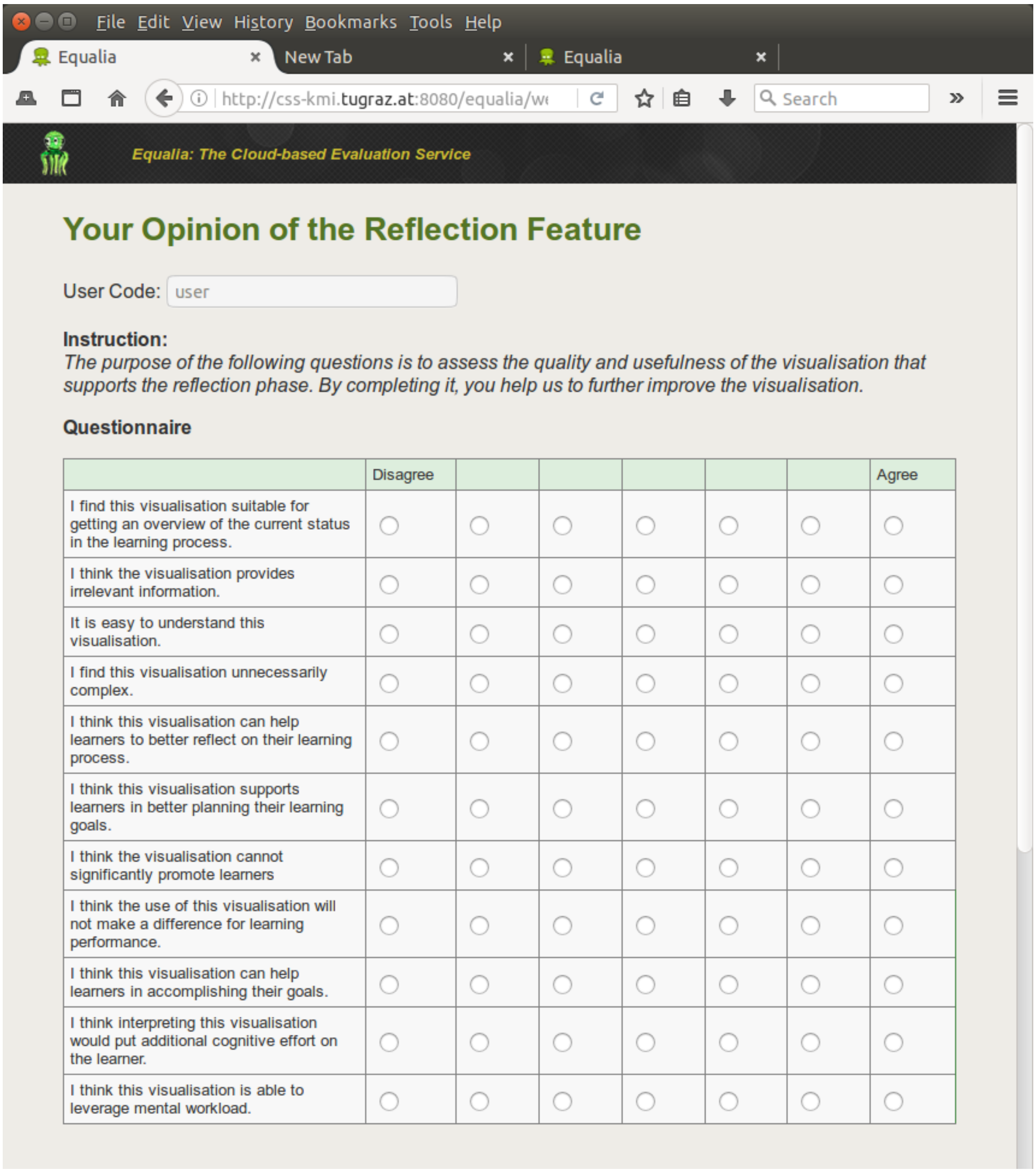
User Code: user

Instruction:
The purpose of the following questions is to assess the quality and usefulness of the visualisation that supports the planning process. By completing it, you help us to further improve the visualisation.

Questionnaire

	Disagree						Agree
I find this visualisation suitable for getting an overview of the current status in the learning process.							
I think the visualisation provides irrelevant information.							
It is easy to understand this visualisation.							
I find this visualisation unnecessarily complex.							
I think it is very easy to plan learning activities with this visualisation.							
I think this visualisation can help learners to better reflect on their learning process.							
I think this visualisation supports learners in better planning their learning goals.							
I think the visualisation cannot significantly promote learners							
I think the use of this visualisation will not make a difference for learning performance.							
I think this visualisation can help learners in accomplishing their goals.							
I think interpreting this visualisation would put additional cognitive effort on the learner.							
I think this visualisation is able to leverage mental workload.							

Figure B.2: Questionnaire: Your Opinion of the Planning Feature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Search

Equalia: The Cloud-based Evaluation Service

Your Opinion of the Reflection Feature

User Code: user

Instruction:
The purpose of the following questions is to assess the quality and usefulness of the visualisation that supports the reflection phase. By completing it, you help us to further improve the visualisation.

Questionnaire

	Disagree						Agree
I find this visualisation suitable for getting an overview of the current status in the learning process.	○	○	○	○	○	○	○
I think the visualisation provides irrelevant information.	○	○	○	○	○	○	○
It is easy to understand this visualisation.	○	○	○	○	○	○	○
I find this visualisation unnecessarily complex.	○	○	○	○	○	○	○
I think this visualisation can help learners to better reflect on their learning process.	○	○	○	○	○	○	○
I think this visualisation supports learners in better planning their learning goals.	○	○	○	○	○	○	○
I think the visualisation cannot significantly promote learners	○	○	○	○	○	○	○
I think the use of this visualisation will not make a difference for learning performance.	○	○	○	○	○	○	○
I think this visualisation can help learners in accomplishing their goals.	○	○	○	○	○	○	○
I think interpreting this visualisation would put additional cognitive effort on the learner.	○	○	○	○	○	○	○
I think this visualisation is able to leverage mental workload.	○	○	○	○	○	○	○

Figure B.3: Questionnaire: Your Opinion of the Reflection Feature

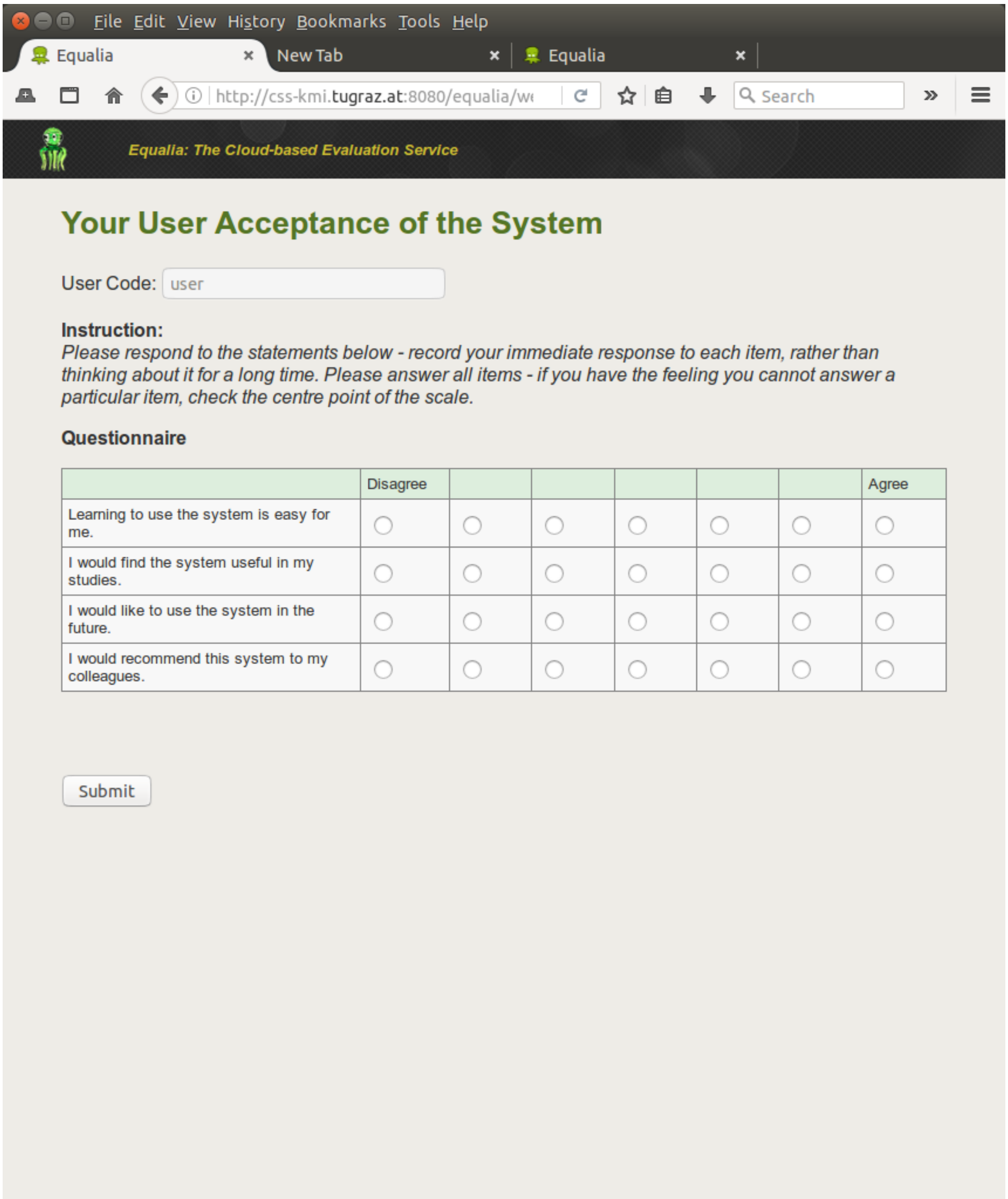
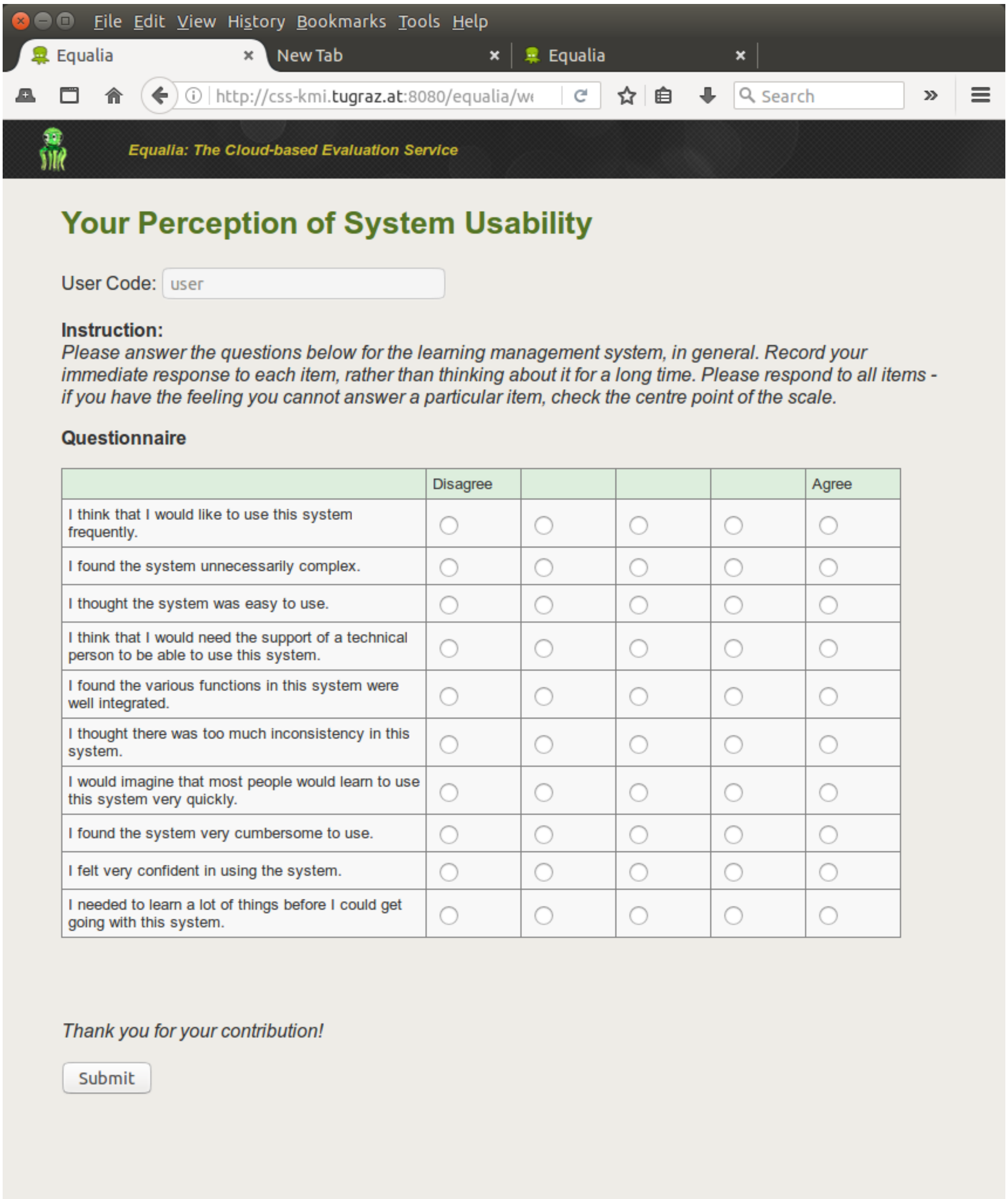


Figure B.4: Questionnaire: Your User Acceptance of the System



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http://css-kmi.tugraz.at:8080/equalia/we

Search

Equalia: The Cloud-based Evaluation Service

Your Perception of System Usability

User Code: user

Instruction:
Please answer the questions below for the learning management system, in general. Record your immediate response to each item, rather than thinking about it for a long time. Please respond to all items - if you have the feeling you cannot answer a particular item, check the centre point of the scale.

Questionnaire

	Disagree				Agree
I think that I would like to use this system frequently.	○	○	○	○	○
I found the system unnecessarily complex.	○	○	○	○	○
I thought the system was easy to use.	○	○	○	○	○
I think that I would need the support of a technical person to be able to use this system.	○	○	○	○	○
I found the various functions in this system were well integrated.	○	○	○	○	○
I thought there was too much inconsistency in this system.	○	○	○	○	○
I would imagine that most people would learn to use this system very quickly.	○	○	○	○	○
I found the system very cumbersome to use.	○	○	○	○	○
I felt very confident in using the system.	○	○	○	○	○
I needed to learn a lot of things before I could get going with this system.	○	○	○	○	○

Thank you for your contribution!

Submit

Figure B.5: Questionnaire: Your Perception of System Usability

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