E-learning has become a major form of education, not limited to the classical forms of education provided by schools, colleges, and universities. E-learning can overcome time and space constraints and can create tailored solutions for specific learner styles and requirements in different situations. E-learning is facilitated through e-learning systems (ELS) comprising what is usually called managed learning environment, virtual learning environment, or learner/content management system, and also learning objects and resource infrastructures. The ELS notion includes learning content, but also the infrastructure that allows content to be created, stored, accessed, and delivered and the learners and the learning process to be managed. The architecture of these ELS is a crucial aspect in this context. Architectures define structural and behavioral characteristics of a system. Architectures define structures that connect an ELS as a software and information system with its instructional and educational context (Bouras & Tsiatsos, 2005).

Architecture is a widely used term that is applied in different situations with different scope. The notion shall be deployed here in a broad, integrative sense covering a range of facets of ELSs:

- Software architecture refers to components and their connection and interaction.
- The information architecture refers to the structure and organization of data and content.
- The information technology architecture puts both software and information architecture in a common framework and relates them to the application context.

Information technology is only one of the aspects that need to be considered from a broad architectural point of view. The notion of a conceptual architecture links aspects of the application context with information technology, e.g. instruction design and software design in the e-learning context. The learning architecture is another notion that aims to connect the educational layer with its underlying software infrastructure.

Although architectures aim to separate different concerns and e-learning infrastructure is often pedagogy-neutral, these types of architectures are inextricably linked. The software architectures need to enable instruction and need to facilitate the learning experience for the aforementioned learning situations, styles, and requirements (Capuano et al., 2005). Interaction is a notion that is central in both instruction and the implementation of software architectures. Architecture is, in addition to its meaning as a structural organization of components, also a notion that is used by software engineers to denote a framework in a wider sense with its tools, techniques, and methods for development.
THE CHALLENGES

The architecture of an ELS needs to provide a conceptual framework for content and software infrastructure in order to implement instruction and sound education, i.e. needs to realize the successful and effective learning experience. Challenges for ELS architecture as a research and development focus arise therefore in relation to the following aspects:

- The introduction of suitable principles and components of the IT architectures of modern and anticipated future ELS.
- The demonstration of how instruction is reflected in IT architectures of ELS, for example, how interaction design is implemented in and enabled by software component interaction.
- The creation of an understanding of how ELS are architecturally designed, implemented, and operated in terms of the instructional and content aspects involved.
- An investigation into the platform technologies that can actually facilitate and implement ELS architectures.

Specifically, common structures in ELS architectures, but also solutions for specific forms such as knowledge-based, distributed, or adaptive applications of e-learning are sought. In another dimension, aspects from foundations to deployment experience to standards need to be investigated. The integrating element of all individual challenges is the architecture notion with its different facets. An overall architectural perspective in a broad sense will ensure a coherent direction of research, but also a broad enough spectrum that will benefit different types of ELS stakeholders such as learners, instructors, administrators, providers, and developers due to the different architectural facets. The aim for researchers and technology developers in this area needs to be to enhance the conceptual understanding, but also to provide practical guidelines that would allow system developers to design their own ELS infrastructure based on advanced techniques and concepts.

Investigations are needed that reflect current practice and advances in the technology and that lay out a path towards advanced solutions that meet the requirements of modern and future e-learning systems and their users.

SEARCHING FOR SOLUTIONS

Architectures of e-learning system have received some attention over the past years—reflected in standardization efforts such as the IEEE Learning Technology System Architecture LTSA (a high-level reference architecture) and SCORM RunTime Environment RTE (an architectural interface specification that defines interactions between learning objects and their deployment infrastructure). However, both are lowest common denominators of technologies in use. Advanced applications require advanced architectural solutions. Some of these are reflected in current activities such as CORDRA (content object repository discovery and registration/resolution architecture), which is an open, standards-based model for how to design and implement software systems for the purposes of discovery, sharing and reuse of learning content. These developments and trends are some of the aspects that will influence architecture solutions for e-learning systems in the future.

Advanced technical solutions and research efforts are needed, based on a reflection of current trends and developments. Advances in learning technology need to be linked with recent software technology, in particular Web and architecture technology as an enabler of the learning experience.
• Technological advances in software architecture (SOA), see e.g. (Avgeriou et al., 2003), and knowledge technologies (ontologies and intelligent agents), see e.g. (Okamoto et al., 2000), can contribute to adequate solutions if these are connected to recent trends in learning technology (personalized, active, and collaborative learning and also synchronous, asynchronous, and blended forms of delivery), see e.g. (De Bra et al., 1999) or (Bote-Lorenzo et al., 2002).
• Activity in terms of standards (e.g., ADL SCORM and IEEE LTSC), which are a reflection of the most common concepts, are another factor influencing future architecture solutions.

ELS and e-learning architectures have been discussed recently in some academic and professional communities, which is reflected in conference and journal contributions, but also by multinational consultancy companies such as IDC and Forrester Research. This book aims to bring together advanced and novel aspects of architectural issues in a comprehensive account, targeting a wide audience of e-learning technology users, developers, and providers.

In order to provide a comprehensive solution of architectural issues in e-learning systems, the following aspects need to be addressed:

• Basic architecture building blocks such as content and infrastructure services, learning objects, and infrastructure components (Pankratius & Vossen, 2003).
• Developer activities that enable the educationally sound assembly and reuse of services, content, and components (Devedzic & Harrer, 2005; Murray, 1999).
• deployment and evaluation to provide quality educational content and services to learners and support for instructors (Tattersall et al., 2005; Weibelzahl & Weber, 2002).
• Knowledge and content solutions based on knowledge architectures and infrastructures based on Semantic Web, intelligent, adaptive, ontology-based, and annotation techniques (Dolog et al., 2004; Woelk & Agarwal, 2002).
• Content and infrastructure aspects focusing on learning objects in their (learner or learning content) management infrastructure (Vossen & Westerkamp, 2004).
• The application and limitations of standards.
• Current trends towards mobile and ubiquitous platforms and devices (Weiser, 1998; Warlick, 2005).

The general theme which guides these solutions is how instructional aspects are reflected by architectural issues. Instruction and learning content—and of course ultimately the learner—always need to be the focus and the drivers of ELS architecture.

Architecture is a notion that is interpreted in many ways in the e-learning context. A systematic organization of the different architectures facets, but also the foundations to applications and standards dimension, results in the following aspects.

• General software architecture frameworks for ELS need to identify the common building blocks of ELS architectures. A comprehensive account of architectural styles can enable the quality-driven development of ELS architectures and systems. Architectural styles are the first step that provides a framework for the definition of functional models and activities. Learning objects as identifiable units of content play a special role as learning content determines and drives the design of architectures. With the recent advent of service architectures, the provision of content as services is a specific aspect.
• Conceptual and learning architectures capture instruction and content development in the context of architecture modeling. In addition to infrastructure-oriented approaches, a development framework and processes also need to be supported for instruction and content. The development of instruction and content needs to be integrated with the software architecture perspective. Content and learning object architectures shift the focus even more towards architectures constructed from learning objects. The reusability is a central aim of learning object developments, which is a consequence of the often complex and costly development of media-rich and interactive learning objects. In particular, active learning objects that provide knowledge-level interactions require adequate support from the infrastructure architecture.

• Another dimension is the management architecture. E-learning systems are often used in a distributed context. Educational offerings can be provides across institutions. The organizational requirements arising from this situation needs to be reflected on the architectural level.

• Architectures for e-learning systems are often characterized by the use of specific techniques or the focus on specific types of learning support. Specific implementation technologies are knowledge-based, intelligent, adaptive, or multimedia techniques. Specific application types are personalized, distributed or collaborative learning.

• Standards and interoperability are central factors that determine the architecture of an e-learning system. Standards often describe reference architectures or standard interfaces that standards-compliant systems are expected to implement. Some example in the educational technology context are the SCORM Runtime Environment (RTE) standard, which defines infrastructure interfaces that enable packaged learning objects to be launched and controlled during their lifecycle. The IEEE Learning Technology System Architecture (LTSA) defines a reference architecture based on common components and their functionality and interaction. CORDRA is a reference architecture for content object repositories that highlights the importance of content objects in e-learning architectures. These domain-specific standards are complemented by a range of platform-specific standards such as Web services and the Semantic Web for the Web platform. This range of standards, in particular those mentioned in the context of educational technology, clearly highlight the importance of architectural aspects for e-learning systems.

A perspective that complements the previous categorization of architectural perspectives is architecture quality and evaluation. Evaluation itself is often the starting point of a cycle of formative evaluations resulting in re-engineered, re-factored evolving systems.

**ORGANIZATION OF THE BOOK**

The book is organized into three parts:

• **Section I:** “Architectural Types” discusses the impact of a number of architectural platforms that have recently emerged, such as services, Grids, mobile systems and podcasting, on e-learning.

• **Section II:** “Software Architecture and Software Engineering” consists of a number of different perspectives on the different stages of software engineering and architecture techniques applied to e-learning systems.

• **Section III:** “Applications and Educational Perspectives” discusses specific educational contexts, the issue of adaptivity and some pedagogical perspectives on e-learning systems and architectures.
Section I. Architectural Types

Chapter I (Moving Towards a Generic, Service-Based Architecture for Flexible Teaching and Learning Activities) discusses service-based architectures to support teaching and learning activities. Based on research on aspects of adaptivity, multi-paradigm support and distribution in the AdeLE project, suggestions for a generic architecture are made.

Chapter II (Collaborative E-Learning System and E-Pedagogy: Learning Resource Infrastructure for Distributed Knowledge Sharing) focuses on the important aspect of collaboration in e-learning systems. A Grid architecture is utilized to implement knowledge sharing. It demonstrates how the pedagogical principle of collaboration can be realized using such an architecture.

Chapter III (Service-Based Grid Architectures to Support the Virtualization of Learning Technology Systems) discusses principles of Grid architecture and how these can be used to support learning content management and learner management systems. The principles of service-based Grid architectures are introduced and it is demonstrated how this infrastructure can be deployed to implement a broker that mediates between common components of an e-learning system.

Chapter IV (From E-Learning to M-Learning: Architectures to Support University Teaching) looks at the recently emerging mobile devices and platforms to support third-level education. Architectures based on wireless technologies are explored in order to provide solutions for asynchronous and collaborative virtual teaching and learning. A case study is used to discuss challenges and possible solutions.

Chapter V (Architectures of Existing and Conceptual Applications of Podcasting in E-Learning Systems) investigates podcasting, which has recently received much attention in the entertainment context, as a specific form of mobile learning. Audio podcasting is reviewed in its impact on pedagogical principles and architectural and infrastructure requirements.

Section II. Software Architecture and Software Engineering

Chapter VI (A Step Towards a Pattern Language for E-Learning Systems) looks at the development of e-learning systems. Focusing particularly on intelligent tutoring systems, a pattern-based development technique, which is widely used in software engineering, is deployed. Common structures at the architecture level can be identified through patterns, for which a pattern language is discussed and a catalogue of patterns is suggested.

Chapter VII (Model-Driven Engineering (MDE) and Model-Driven Architecture (MDA) Applied to the Modeling and Deployment of Technology Enhanced Learning (TEL) Systems: Promises, Challenges, and Issues) provides another perspective on the development of e-learning systems. Model-driven architecture is presented in its principles and related to well-known development approaches for teaching and learning content and systems.

Chapter VIII (Accessibility, Digital Libraries, and Semantic Web Standards in an E-Learning Architecture) looks at the issue of standardization in the context of e-learning systems development and deployment. An overview of learning technology standards is given. Their impact on interoperability and architectures for e-learning systems is discussed using a learning object repository architecture for illustration.

Chapter IX (End-User Quality-of-Experience Aware Personalized E-Learning) addresses the evaluation of e-learning systems. In addition to pedagogical qualities, technical aspects such as performance are gaining importance in particular in distributed and mobile environments. A quality-of-experience architectural layer to monitor and evaluate quality is proposed and illustrated in the context of adaptive learning content delivery.
Chapter X (E-Learning Systems Reengineering: Functional Specifications and Component-Based Architecture) focuses on re-engineering of existing e-learning systems. A re-engineering method based on two reference models—a functional and a component-based view—is introduced. A staged development, resulting in a layered architecture of interoperable services, is presented.

Section III. Applications and Educational Perspectives

III.a Specific Application Contexts

Chapter XI (An Integrated Architecture for Supporting Vocational Training) investigates the needs and architectural requirements of vocational and adult learning and training. A development framework and an architecture based on specific vocational training services that enables both synchronous and asynchronous forms of collaborative learning and training is proposed.

Chapter XII (A Generic Platform for the Systematic Construction of Knowledge-Based Collaborative Learning Applications) looks at group activities and interactions in the context of collaborative learning. The requirements of an infrastructure for the management of knowledge to support these group activities are discussed. An information architecture in the form of a computational model that structures required information and knowledge.

III.b Adaptivity

Chapter XIII (From Learning Objects to Adaptive Content Services for E-Learning) presents a discussion of the important principle of adaptivity for e-learning. Adaptive content services are proposed. Two widely known systems, APeLS and Knowledge Tree, are used to elicit the specific challenges of adaptivity and possible solutions in service-based architectures.

Chapter XIV (An Adaptive E-Learning Platform for Personalized Course Generation) addresses adaptivity from the perspective of the information architecture. The different information models, their ontological support and their integration are discussed. The Diogene architecture is used to discuss information integration and access in this context.

III.c Education and Content Perspective

Chapter XV (Pedagogical Scenario Modeling, Deployment, Execution, and Evolution) presents an investigation into the development of e-learning systems driven by pedagogical scenarios as a specific form of learning design. Based on the IMS Learning Design and embedded into model-driven engineering this realizes a development method for e-learning systems.

Chapter XVI (Impact of Context-Awareness on the Architecture of Learning Support Systems) aims to draw attention to the notion of situatedness in the context of learning. An ontology-based formalized notion of context and context-awareness, which is introduced to denote the link between content and its context, are looked at in order discuss the impact on architectures of learning support systems.

Chapter XVII (Design and Evaluation of Web-Based Learning Environments Using Information Foraging Models) investigates information foraging as a specific aspect of the information architecture of e-learning systems. Information foraging is an information seeking and retrieval technique that is applied to learning content. A tool is presented to support the development and evaluation of e-learning environments.
REFERENCES


