# Standards for Ambient Learning Environments

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**Abstract:** The integration of information systems is not a new challenge. As one instrument, standards provide interfaces for integrated information systems. With regard to the recent advent of modern technologies, such as Radio Frequency Identification (RFID) or Wireless Sensor Networks (WSN), additional standards must be taken into account. The main objective of this paper is to show an approach to integrate ambient solutions for learning and business processes and the corresponding applications. After introducing ambient learning, current technology, data, infrastructure, and learning technology standards are reviewed. We present a standard-based ambient learning environment being implemented at the University of Duisburg-Essen.

## 1 Introduction

In the last years, a variety of e-learning and knowledge management solutions have been developed for workplace-oriented learning. The goal of those concepts is to provide practical solutions for problems in daily business processes. In this area, two trends can currently be observed: e-learning and knowledge management converge into integrated solutions [RMW05]. E-learning has shifted from the traditional course-based structure to providing knowledge "on demand" [KM00]. Furthermore, knowledge management solutions are integrated into learning processes. However, this integration leads to several challenges: knowledge management systems and e-learning systems are currently mostly stand-alone systems. Neither the processes nor the information systems are integrated. Since the re-use of knowledge and the appliance of competencies are the most important issues for learning and knowledge management [SK02], interoperable solutions have to be developed, both on the conceptual and implementation level. As the second trend, e-learning (m-learning) and knowledge management solutions have been developed using mobile technologies [Le02, Tr03]. These solutions shall either improve the flexibility of the learning process or support learners in mobile workplaces. As the next generation of m-learning, ambient learning provides solutions which are embedded in the environment of the learner [Pa05]. Ambient learning environments provide contextualised, personalised knowledge for learners. However, both mobile and ambient learning environments are not yet widely used and adopted.

Based on these trends, we show a solution how mobile and ambient learning environments can be developed in an interoperable way. After an introduction into ambient learning, we show standards on four levels: how can application, middleware, data, and device standards support the interoperability of ambient learning environments. Based on those standards, we present an architecture of ambient learning environments leading to interoperable and reusable solutions. We show how this architecture improves the development of ambient learning environments by a sample implementation.

## 2 Ambient Learning Environments

Workplace-oriented learning has become one of the main usage scenarios for e-learning [CW02]. Ambient learning is used to support informal and non-formal learning processes in this setting. In the following, we show how ambient learning can support learners in their working environment.

### 2.1 Ambient Learning

New information and communication technologies (ICT) provide new opportunities for an advanced concept for providing knowledge to learners [Pa05]. Ambient learning denotes new ICT embedded into the environment leading to advanced e-learning scenarios. The main difference to mobile learning (m-learning) is that so solely mobile devices are used but information the context / environment is incorporated. Ambient intelligence technologies can be described by five key characteristics (Table 1).

| | |
|---|---|
| Embedded | Integration of (different) network devices into the environment |
| Context-aware | Recognition of learners and their situation by these devices |
| Personalized | Tailoration towards the learners needs |
| Adaptive | The devices can change in response to the learners needs |
| Anticipatory | Anticipation of the learners desires without conscious mediation |

Table 1: Key elements of Ambient Intelligence [Aa03]

By combining the characteristics of ambient intelligence and the requirements of learning paradigms, a scheme for ambient learning can be described: Firstly, ambient learning has to be permanent. The learner’s progress and processes can be recorded on a regular schedule. Furthermore, the ambient learning environment needs to offer access to any content, such as documents, data, or video. The learning content is provided on request of the learner. Thus, the learning process can be self-directed. Additionally, a learner shall get content wherever he is, so that an immediately access to the learning environment is guaranteed. By offering the opportunity to interact with experts, tutors, or other learners, the ambient learning process shall integrate interactivity. Moreover, the learning process has to be embedded in daily life situations to confront the learner with authentic issues and problems. Lastly, the learner needs the opportunity to get the right information at the right place in the right way [Bo05]. Context aware services shall provide e-learning-services integrating high quality learning content [Pa05]. Based on the specific context of a learner (e.g., a consultant, who is most of the time travelling) and the personal qualifications, the learning content could be downloaded from a knowledge base to a mobile device and is displayed to the learner automatically [Pa05]. However, it is necessary to analyse the didactical and organizational influence factors, such as the context of the learner. The next section proposes a framework which deals with the corresponding conceptual and technological analysis of ambient learning.

### 2.2 Ambient Learning Framework

In this section, we introduce our approach for a framework which maps the influencing dimensions, such as actors, their competencies, or technologies, in an ambient learning scenario. Furthermore, the framework addresses the individual competence development by describing and utilising the context of the learner to enable personalisation and adaptation to specific learning situations respectively environments. This idea is supported by integrating the building blocks of knowledge management [PR00]. The building blocks of knowledge management offer the opportunity to structure knowledge specific tasks to logical phases. The proposed ambient learning framework (Figure 1) is a centralised mapping of six perspectives that have to be regarded when introducing learning environments supported by ambient intelligence. These perspectives (*actors/competencies, ambient technologies, mobile technologies, case studies,* and *context*) are described in the following.

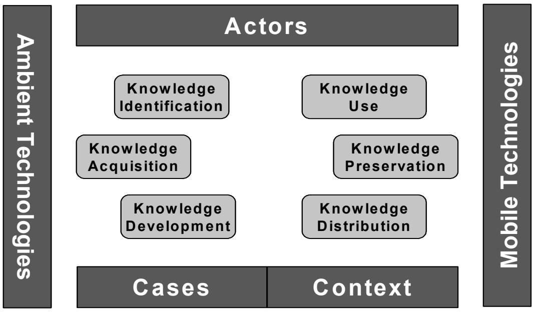


Figure 1: Ambient Learning Framework

The *actor's* (learner's) preferences, competencies, and experiences are important criteria regarding the characteristics of an actor. Besides, the characteristics of the actors have direct constraints to the context as well (e.g., what kind of learning is preferred by a salesman, who doesn't come often into office?). Therefore, the framework maps the *context* of an ambient learning environment. The context contains the main influence factors of learning processes, as it covers a broad range of factors, like socio-cultural and organisational aspects. Hence, the ambient learning environment is strongly dependent on the context in which the actors demand learning materials. Thus, we integrated a view into the framework that integrates professional experiences represented in case studies. *Case studies* can be used to derive adequate solutions for new learning processes. To capture a technical point of view, we focused on *ambient* and *mobile technologies*. M-learning contains all scenarios using mobile devices. Complementary, ambient learning technologies are attached to a certain location (e.g., a certain position within a school) or object (e.g., a machine). All those different perspectives on ambient learning are associated to the core elements in the framework: the *building blocks of knowledge management* [PR00]. By attaching the building blocks to the different perspectives, we aim on the individual's context-sensitive learning processes. Additionally, those building blocks structure the learning activities.

## 3. Standards

With regard to the above mentioned framework various levels of integration must be taken into account, such as applications, data, and technologies. Therefore, we present a survey of standards to enable developers to design an interoperable ambient learning environment.

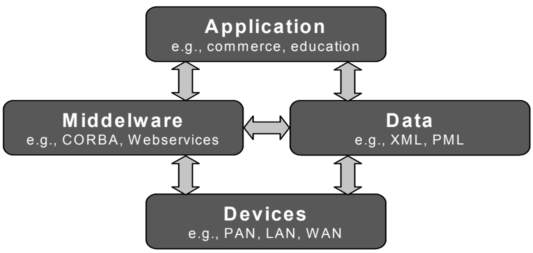


Figure 2: Standards

We focus on four levels: *devices*, *data*, *middleware* and *application* (Figure 2): Standards on the *devices* level facilitate the physical integration of information systems (e.g., business information systems, etc.). Thereupon, the exchange and sharing of specific content within an ambient learning environment demands compatible *data* standards. To obtain integrated ambient learning environments appropriate *middleware* must be taken into account additionally. The corresponding infrastructure standards deal with the interoperability of software applications and database systems as well as the coordination of functions that manage, control, and monitor ambient learning processes. With regard to the highly complex domain of ambient learning environments, standards in the area of business information systems integration as well as specific learning technology standards must be applied on the *application* level.

### 3.1 Devices

In the context of this paper, devices are defined as all entities / objects which are able to exchange data within the ambient learning environment via computer networks. E.g., a single RFID tag can be a device as well as a mobile telephone or a personal computer. Consequently, ambient intelligence technology standards mainly focus on computer networks and communication between the various involved devices. In principle, the

Open System Interconnection (OSI) model (ISO 7498) represents the corresponding theoretical framework [CV04]. The ISO/OSI reference model is a hierarchical structure of seven layers that defines the requirements for communications between two computers or more general devices. The physical and data link layer can be classified into protocols for Personal Area Networks (PAN), Local Area Networks (LAN), and Wide Area Networks (WAN) [MHP05]. All of them can be cable-bound or wireless and all of these protocols have varying transfer rates and ranges.

In ambient learning environments mobile technologies should be emphasized particularly, e.g., Bluetooth to attach the frequency of Radio Frequency Identification (RFID) chips to wireless protocols in PAN. Amongst the WAN protocols the Asynchronous Transfer Mode (ATM) as well as the Fibre Distributed Data Interface (FDDI) are examples for cable-bound networks. Besides, Wireless Application Protocol (WAP), General Packet Radio Service (GPRS) and Universal Mobile Telecommunication System (UMTS) are common exponents for wireless protocols. (For further discussion cf., e.g., [MHP05]).

### 3.2 Data

The exchange of data between various information systems and devices within an ambient learning environment requires appropriate data standards. Commonly, four groups of exchange formats can be distinguished: Comma Separated Values (CSV), Electronic Data Interchange (EDI), Extensible Markup Language (XML), and miscellaneous [Le04]. The dominant exponent of these standards is XML. Even though it has some weaknesses this very flexible text format is playing an increasingly important role in the exchange of a wide variety of data in computer networks [W3C06].

The XML-based Wireless Markup Language (WML) currently is the primary content format for devices that implement the WAP specification (section 3.1), such as mobile phones. Moreover, recent ambient specific standards have been established, e.g., the Physical Markup Language (PML) [Br01]. PML has been designed to standardize the description of physical objects for use in remote monitoring and control of the physical environment. The development of PML ended with the foundation of EPCglobal. The EPC Information Service brings different data to the involved objects applying a specific transponder, e.g., a RFID-transponder. It comprises historical information which enables track and trace processes. Furthermore, general information of various devices or from different data sources is available [Fl05].

### 3.3 Middleware

There are various approaches to middleware technology, e.g., Remote Procedure Call (RPC), Distributed Component Object Model (DCOM), or CORBA. CORBA is probably the most common exponent of infrastructure standards. Recent middleware technologies involve using Web services as part of a service-oriented architecture as a means of integration [De03].

In principle, an ambient learning specific middleware could be understood as a further development of common middleware approaches for distributed systems [CDK98]. Contrary to the rather static information systems' infrastructures ambient learning environments have to deal with a dynamic infrastructure, e.g., blackouts of various devices or the integration of additional devices must be clearly specified. Furthermore, the handling of location data derived from sensors in the physical world with regard to the management of context-aware applications has to be taken into account.

Currently, there are no formal infrastructure standards in the fields of ambient intelligence or ubiquitous computing. There are only various projects underway that aim to develop specific (more or less proprietary) approaches. E.g., Schoch [Sc05] analyzed fourteen ubiquitous computing middleware concepts or Römer et al. [RKM02] identified various projects to develop middleware for Wireless Sensor Networks (WSN). With regard to the involved project partners, e.g., Microsoft – EasyLiving [Br00] or HP – CoolTown [KB01], the next step will (only) be some market-based de-facto standards.

### 3.4 Application

The application level focuses on specific standardisation activities in various domains, e.g., education. The corresponding learning technology standards are widely accepted specifications to describe the components and characteristics of learning environments. Their main goal is to develop interoperable systems. Since our ambient learning framework shall be used to reach comparable results, we suggest a technical implementation based on existing standards.

Different standards have been developed for the description of content (Learning Object Metadata, LOM [IEE02], for the interaction between learning management systems (LMS) and learning objects (Sharable Content Object Reference Model, SCORM [DT04]), for didactical scenarios (IMS Learning Design [IMS02]; DIN Didactical Object Model [DIN04]), and for actor / user modelling (Learner Information Package, LIP [IMS01]). These standards provide a basis for the reuse, recombination, and re-contextualisation. However, specifically for the field of mobile and ambient learning several issues are not yet addressed (section 3.3). The use of a variety of devices (e.g., handhelds or SmartPhones) cannot be modelled in the above mentioned standards. As examples, location and synchronisation aspects are not covered in standards like LOM or IMS Learning Design:

- *IEEE Learning Object Metadata:* This standard includes a minimal set of attributes to manage and locate learning objects [IEE02]. LOM does work well within a browser-based e-learning context, where users have a standardised platform to identify the content they need within a repository. Users of ambient and mobile devices need the didactical context of each learning object to be able to even retrieve useable learning objects for their specific context. To accommodate these additional needs, LOM supports local extensions, but there is no extension capable of providing the information recently. Therefore, it seems much more promising to use LOM within IMS LD for ambient learning environments.

- *IMS Learner Information Package:* IMS LIP is designed to describe the learner, to record and manage learning-related history, goals and accomplishments [IMS01]. As with IEEE's LOM, IMS LIP is designed for a store and retrieve based scenario and for instance does not include dynamic information on the user's preferred devices.

- *IMS Content Packaging:* "The objective of the IMS CP Information Model is to define a standardized set of structures that can be used to exchange content." [IMS05] In m-Learning and ambient learning the need for learner individual content packages is more evident, as learners cannot easily stay connected to the internet while changing their location. Content packages designed for m-learning have to address this to make full use of their potentials.

- *IMS Learning Design:* IMS LD is a specification describing pedagogical concepts and promoting the exchange and interoperability of e-Learning activities [IMS02]. Of particular interest to ambient learning are the services within an environment, which specify the software and other services like tutoring available within such an environment. Learner profiles using LIP can be matched with described learning processes to see if a learner can actually use a learning resource. This is generally a difficult task, as there is no common taxonomy for knowledge or learning objectives. In a specific learning environment a taxonomy can already be present, for instance corporate educational profiles can be used to build such taxonomy. But even without a predefined taxonomy the prerequisites make the learning process much more transparent for learners.

Finally, e-learning standards focus on how authors of learning objects designed their objects. However, in an ambient learning environment where users are expected to learn in various locations and in different contexts, it is more important to describe the usage scenarios. Additionally, in e-learning learners are usually not expected to add to the knowledge base, which is a key feature of the presented framework (section 2.2).

## 4. Sample Implementation of an Ambient Learning Environment

In this section, we introduce a sample implementation of an ambient learning environment. This learning environment integrates essential components of the ambient learning framework described in section 2.2. We applied this framework as a roadmap to design and implement: *An introductory course on Business Information Systems*. Two aspects are crucial for our prototype: How do standards improve interoperability of the components? How can standards improve adaptability for learners in different contexts?

The first goal of the sample implementation is the analysis of adaptability. Potential users of the course are three target groups: 1) First semester students to receive additional materials supplementing the face-to-face lectures; 2) High school students to raise awareness and interest in the subject of Business Information Systems as potential new students; 3) Professionals working in the field of information systems to provide practical solutions and knowledge for problems in their working environment. This target group therefore does not participate in the course itself but uses its content from a knowledge management perspective.

The need of satisfying three target groups leads to different challenges: How can we present learning content which provides the right amount of information and knowledge to each of the three groups (e.g., a student at university has different insights and previous knowledge than a school grade student)? How can we integrate the additional information our target groups require into the learning content?

To answer those questions, we firstly developed an e-learning environment applying learning technology standards (section 3.4), e.g., IMS LOM, to create the initial contents and activities, accessible to all target groups. In the next step, the e-learning course was enriched with mobile technologies using appropriate standards on the devices (section 3.1) as well as on the middleware level (section 3.3) to allow ubiquitous access. The main aspect of our analysis was adaptation of content, didactics, and technologies which lead to the described sample of an ambient learning environment. In the following, we will show the already implemented components of our ambient learning framework.

**Knowledge:** The main question in this framework component is how knowledge and knowledge-sharing activities should be represented and used in an adaptable way for all target groups and different devices. As a general principle, the course is structured in short modules to ease the transfer to mobile devices and to provide knowledge for specific problem fields. The learning content was designed as an IMS LD package (section 3.4), which represents the initial knowledge base for the course. To ease the data exchange, each content asset is structured using a TeachML [WL01] based approach. This enables all systems and actors to easily access the content structure. Additionally, it enables the transformation of content for different media channels, like xHTML or WML (section 3.2). Figure 3 shows an example of the new content embedded in the IMS LD package.

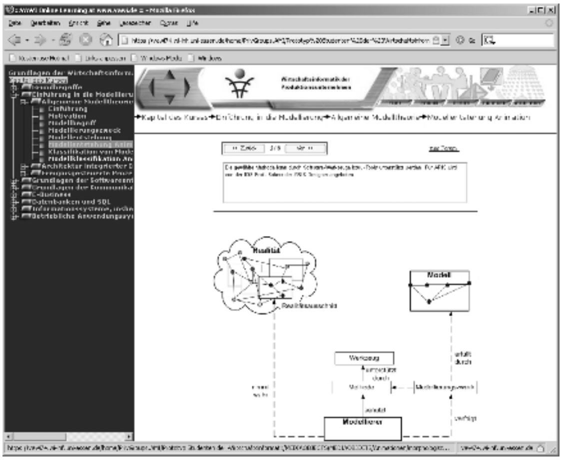


Figure 3: Content package view

A topic map [ISO04] was used to connect the knowledge represented in the package with other courses, departments and researchers at the business information system department at our university. Additionally, the developed topic map also included information which content could be transformed for the different media channels to identify content assets which cannot be transformed to, e.g., mobile phones.

The IMS LD package (section 3.4) is imported into a learning management system called Open-sTeam [Es06], which not only allows the students to browse through the material using the predefined learning structure, but also enables learners to restructure the content for themselves and comment on each content-asset individually. Using the IMS LD standard enables the students to improve the adaptability of the presented content to their preferences by restructuring the content and adding to it. Adopting corresponding standards as described in section 3, we consequently support interoperable information systems. To enable knowledge sharing, social software tools – like wikis and discussion forums – were also included to give the learners an additional opportunity for collaboration. We integrated various knowledge management functionalities in our ambient learning environment. Applying Web service standards on the middleware level (section 3.3) the ambient learning environment integrates various information systems classes, e.g., knowledge management systems (KMS) or learning management systems (LMS).

**Actors / Competencies:** Adaptation is done based on the learner's preferences and characteristics. Therefore, we suggest a corresponding representation based on standards, e.g., IMS LIP (section 3.4). The first step was a comprehensive analysis of all involved actors to identify the needs and requirements of each target groups. In our implementation, we identified the problem that awareness aspects are not included in IMS LIP. Since one of the main aspects of our ambient solution in the LMS Open-sTeam is collaboration using awareness functionalities, we had to implement a proprietary solution. Focussing the professionals target group, we identified diverse data standards in the field of competency profiles respectively human resources management, e.g. CSV, variants of EDI transaction sets, vendor-specific XML, and IMS LIP (section 3).

These standards can be used to identify and recommend experts, who are currently logged in the learning management system for the topic viewed. Therefore, we suggest to use IMS LIP based competency profiles to improve information system integration and connecting to external systems: Typically, a learning management system and a human resource management system require the same personal records, e.g., name, gender, role, competencies, etc. This maintained data is passed from the human resource management system to the learning management system. After course / training completion corresponding information is returned to the human resource management system.

**Ambient technologies:** As a base for ambient technologies our technical design includes Bluetooth based stations set up at different locations on the campus, which we intend to use for ambient learning scenarios. Thereby, we apply various standards on the devices level (section 3.1) to integrate PAN into LAN. As a first example, we provide a Web service-based middleware (section 3.3) which integrates the applied devices and the learning management system. This offers, the opportunity, e.g., to directly evaluate the ongoing lectures. Consequently, this interoperable approach provides personalized, device-dependent information services about our lectures within the ambient learning environment.

**Mobile Technologies:** The main goal is to enable the transformation of content and activities into mobile scenarios. Mobile technologies were included for both, the predefined IMS LD content (section 3.4) and the dynamic content developed within the wikis and discussion forums. Thus, we implemented an ambient specific middleware, which supports data exchange and the interoperability of software applications and database systems in heterogeneous computing environments. The learning package provided structured content assets. Two aspects were focused: Firstly, each content-asset has to be evaluated whether it can be used on a mobile device within the didactic structure depicted in the IMS LD package. Secondly, a technical review with regard to appropriate data standards (section 3.2) proves if the automated transformation for the client device is possible. Regarding didactics, it was important whether the actor's roles can be supported on the mobile device. As an example, some parts of the design required the lecturer to moderate chats, wikis or discussion forums. While transforming the content is possible in most cases editing and moderating was out of scope with the mobile phones the lecturer actually used. Thus, they were required to use their laptop or desktop computer for these tasks and no WAP interface was generated for this role. The data, which role could be done mobile, was one of the requirements we added to our topic map to keep the information as flexible as possible. This covers one of the gaps within learning technology standards (section 3.4). As an example, the Web service-based middleware (section 3.3) as well as corresponding data exchange standards (section 3.2) mobile representations were generated as news forum. This integrated solution was used to publish all appointments and deadlines for the learning environment and for all definitions within the content-assets. These are published using xHTML, or WML. While the representation of the content within the learning design was rather straight forward, the dynamic content produced by the learners was more of a challenge. In our initial implementation, the lecturers had to moderate the editing of the topic map to include dynamic content within its design. The Open-sTeam environment does provide a technical base for inheriting attributes from the learning context. In our future implementation, we will enhance the learning environment by adding inherited attributes for dynamic content to the topic map to ease the learning experience.

As a conclusion, the above described components of an ambient learning environment can be implemented using standards from the devices level up to the application level. Our prototype has shown that specifically mobile and ambient solutions require extensions to existing standards (section 3.4). However, the presented sample implementation can serve as a prototype for a standard-based solution leading to comparable, interoperable environments which can be transformed for different contexts as well as applying various devices.

## 5. Conclusion and Further Research

In this paper, we provided conceptual and technological solutions for an ambient learning environment. We introduced the ambient learning framework (section 2.2) mapping the dimensions of ambient learning scenarios. With regard to our ambient learning framework, different levels of integration have to be taking into account: devices, data, middleware, and application (section 3). By applying corresponding standards to the ambient learning framework, we created an architecture for interoperable implementations of ambient learning environments (section 4). We described a sample implementation of an ambient learning environment, which was designed along our ambient learning framework. With this sample implementation we want to analyse the appropriateness and the usefulness of standards and architecture for adaptation purposes. First experiences have shown the usefulness of standards for adapting and contextualising, but also proofed that there is a need to better support highly dynamic environments. New social software tools additionally challenge the way standards are used by allowing each learner to individually add to the knowledge base. Finally, the learner's acceptance and awareness are important aspects when introducing ambient learning environment. Privacy and security policies are not yet addressed appropriately. A discussion concerning ambient intelligence is already not only a question of standardisation issues. It is also an interdisciplinary field that needs to implicate social, economic, and ethical aspects.

## References


[Aa03] Aarts, E.: Technological Issues in Ambient Intelligence. In (Aarts, E.; Marzano S. Eds.): The New Everyday: Ambient Intelligence. 010 Publishers, Rotterdam 2003, pp. 12-17.

[Br00] Brumitt, L. B. et al.: Ubiquitous Computing and the Role of Geometry. In: IEEE Personal Communications, 7 (2000) 5, pp. 41-43.

[Bo05] Bomsdorf, B.: Adaption of Learning Spaces: Supporting Ubiquitous Learning in Higher Education. http://drops.dagstuhl.de/opus/volltexte/2005/371/pdf/05181.BomsdorfBirgit.Paper.371.pdf, cited 2006-07-04.

[Br01] Brock, L. D.: The Physical Markup Language. http://archive.epcglobalinc.org/publishedresearch/MIT-AUTOID-WH-003.pdf, cited 2006-07-11.

[CV04] Chen, D.; Vernadat, F.: Standards on enterprise integration and engineering – state of the art. In: International Journal of CIM, 17 (2004) 3, pp. 235-253.

[CDK98] Coulouris, G.; Dollimore, J.; Kindberg, T.: Distributed Systems: Concepts and Design. Addison Wesley, Harlow 2001.

[CW02] Collis, B.; Winnips, K.: Two scenarios for productive learning environments in the workplace. In: British Journal of Educational Technology, 33 (2002) 2, pp. 133-148.

[De03] Deitel, M. H. et al.: Web Services: A Technical Introduction. Pearson Education, London 2003.

[DIN04] Deutsches Institut für Normung e.V.: Aus- und Weiterbildung unter besonderer Berücksichtigung von e-Learning – Teil 2: Didaktisches Objektmodell – Modellierung und Beschreibung didaktischer Szenarien. Beuth, Berlin 2004.

[DT04] Dodds, P.; Thropp, E. S.: Advanced Distributed Learning Initiative: Sharable Content Object Reference Model – 2004 Overview. http://www.adlnet.org/, cited 2006-07-06.

[Es06] *Eßmann, B.:* Mobilität in der kooperativen Wissensarbeit: Entwicklung einer Musterarchitektur für mobil-verteilte Wissensräume. http://ubdata.uni-paderborn.de/ediss/17/2006/essmann/, cited 2006-07-04.

[Fl05] Flörkemeier, C.: EPC-Technologie – vom Auto-ID Center zu EPCglobal. In (Fleisch, E.; Mattern, F. Eds.): Das Internet der Dinge. Springer, Berlin 2005, pp. 87-100.

[ISO04] ISO/IEC JTC 1/SC 34: Topic Maps – XML Syntax. http://www.jtc1sc34.org/repository/0495.htm, cited 2006-07-04.

[IEE02] IEEE Learning technology Standards Committee: Learning Object Metadata Standard, IEEE 1484.12.1-2002, 2002.

[IMS01] IMS Global Learning Consortium: IMS Learner Information Packaging Information Model Specification. http://www.imsproject.org/profiles/lipinfo01.html, cited 2006-07-03.

[IMS02] IMS Global Learning Consortium: IMS Learning Design Information Model. http://www.imsglobal.org/learningdesign/ldv1p0pd/imsld_infov1p0pd.html, cited 2006-07-03.

[IMS05] IMS Global Learning Consortium: IMS Content Packaging Information Model. http://www.imsglobal.org/content/packaging/cpv1p2pd/imscp_infov1p2pd.html, cited 2005-07-04.

[KB01] Kindberg, T.; Barton, J. J.: A Web-Based Nomadic Computer System. In: Computer Networks 35 (2001) 4, pp. 443-456.

[KM00] Kraemer, W.; Milius, F.: Vom Lernen auf Vorrat zum Lernen auf Abruf: Anwendungspotentiale von E-Learning in Industrieunternehmen, In: Industrie Management, 16 (2000) 4, pp. 25-30.

[Le02] Lehner, F.: Mobile Knowledge Management. In (Hartmann, D. Ed.): Geschäftsprozesse mit Mobile Computing. Vieweg Verlag, Wiesbaden 2002, pp. 153-172.

[Le04] Leukel, J.: Katalogdatenmanagement im B2B E-Commerce. Josef Eul Verlag, Lohmar/Köln 2004.

[MHP05] Maier, R.; Hädrich, T.; Peinl, R.: Enterprise Knowledge Infrastructures. Springer, Berlin 2005.

[Pa05] Paraskakis, I.: Ambient Learning: a new paradigm for e-learning. http://www.formatex.org/micte2005/229.pdf, cited 2006-07-04.

[PR00] Probst, G.; Romhardt, K.: Building Blocks of Knowledge Management – A Practical Approach. John Wiley & Sons, Hoboken 2000.

[RMW05] Ras, E.; Memmel, M.; Weibelzahl, St.: Integration of E-Learning and Knowledge Management – Barriers, Solutions and Future Issues. In (Althoff, K.-D. et al. Eds.): Professional Knowledge Management. Lecture Notes in Artificial Intelligence Vol. 3782. Springer, Berlin 2005, pp. 155-164.

[RKM02] Römer, K.; Kasten, O.; Mattern, F.: Middleware Challenges for Wireless Sensor Networks. In: Computing and Communications Review, 6 (2002) 4, pp. 59-61.

[Sc05] Schoch, T.: Middleware für Ubiquitous-Computing-Anwendungen. In (Fleisch, E., Mattern, F. Eds.): Das Internet der Dinge, Springer, Berlin 2005, pp. 119-140.

[SK02] Sridharan, B.; Kinshuk: Knowledge Management and Reusability in Internet Based Learning. In (Kinshuk et al. Eds.): Proc. of the International Conference on Computers in Education, Los Alamitos, CA: IEEE Computer Society, 2002, pp. 1398-1399.

[Tr03] Trifonova, A.: Mobile Learning – Review of the Literature. http://eprints.biblio.unitn.it/archive/00000359/01/009.pdf, cited 2006-06-28.

[WL01] Wehner, F.; Lorz, A.: Developing Modular and Adaptable Courseware Using TeachML. In: Proceedings of ED-MEDIA, World Conference on Educational Multimedia, Hypermedia & Telecommunications, Tampere, Finland 2001, pp. 2013-2018.

[W3C06] W3C: Extensible Markup Language (XML). http://www.w3.org/XML, cited 2006-07-11.