AMBIENT LEARNING ENVIRONMENTS - MULTIMODAL INTERACTIVE TEACHING AND LEARNING ENVIRONMENTS WITH LOW THRESHOLD, WIDE WALLS, AND HIGH CEILING

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Abstract

During the last decade various digital educational platforms have been developed and put into place and operation. Besides communication platforms, user and content management systems have been created and used widely. These systems have often been called Learning Management Systems (LMS) to focus on the processes of teaching and learning. At about the same time Immersive Virtual Learning Environments (Immersive VLE) have been built and used to bring teachers and learners into virtual digital contexts of artificial worlds and avatars. The contribution will discuss why all these and similar approaches are highly technology-centered, creating a basically wrong understanding of learning in a world of highly interactive technologies. To liberate from such approaches we will start with the concepts of "ubiquitous computing" and "disappearing computers" merging them with basic learning theories, like "collaborative self-directed learning" and "post-constructivism", into a system architecture we call Ambient Learning Environments (ALE) connecting to relevant real-world contexts ("Lebenswelt"). With Ambient Learning Spaces (ALS) we developed a prototype of an ALE that meanwhile has been used and studied in schools and museums for more than ten years. Initial ideas, the evolution of the system, and experiences from case studies will be discussed to illustrate the concepts. The ALS system architecture will be shown and proposed as a blueprint for future ALEs.

Keywords: Digital Technologies for Learning, Learning Management Systems, Virtual Learning Environments, Ambient Learning Spaces, Ambient Learning Environments.

1 INTRODUCTION

In 1991 Mark Weiser noted *"Most important, ubiquitous computers will help overcome the problem of information overload. There is more information available at our fingertips during a walk in the woods than in any computer system, yet people find a walk among trees relaxing and computers frustrating. Machines that fit the human environment, instead of forcing humans to enter theirs, will make using a computer as refreshing as taking a walk in the woods."* [1]. This vision can be translated into our current world as connected digital technologies that will be ubiquitously available in different device sizes and form factors fitting any time and any place. Weiser called these interaction systems *tabs*, *pads,* and *boards* coming close to today's smartphones, tablets, and large screens. This can be enriched by immersive devices and digital installations like theatres, domes, or head-mounted displays. Bringing such technologies to learning and teaching we lay a foundation for pervasive ubiquitous computing that focuses on content and use instead of technology. In this sense, Mark Weiser and later Donald Norman [2] were discussing *"disappearing computers",* i.e. computers that find their application and meaning in everyday life ("Lebenswelt") in a natural situated way, or, as Weiser put it [1]: *"The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it."*

We can imagine that learners are embedded in shell-like embedding interactive media and physical spaces. The learners will be enabled to use these interactive media in any physical context. Some of these media will be more of an abstract type like virtual worlds; others can be closely connected to the physical world like in augmented realities. Computers themselves will only be noticeable as presenters (displays) and sensors (controls) of these interactive media. The learners will be interacting through the blend of digital media and physical objects within certain environments.

As learners are interacting in this media-enriched physical world for the purpose of perception and action with meaning, the role of *semantics* has to be clarified. If we assume learning as a post-constructivist process, learners build up mental models as cognitive structures to understand, authenticate, and reconstruct their representation of the world. Thus we need to bridge from the physical world through the media to these knowledge representations [3]. Connecting media to knowledge creates *Knowledge Media* ([4], [5])*,* where *Media Objects* are related to *Knowledge Entities.* This means that a digital

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learning environment needs to be *knowledge-sensitive,* where interactive media leads to knowledge and knowledge leads to the media.

2 EDUCATIONAL PLATFORMS

Digitization of teaching and learning was accompanied by the development of digital platforms supporting educational activities as well as storing teaching and learning materials.

2.1 Learning Management Systems (LMS)

The main type of digital support platform in the area of computer-supported teaching and learning has been *Learning Management Systems (LMS)* supporting mainly activities like:

- User and role management
- Course management, including scheduling, tracking and reporting
- Storage and access of course materials
- Communication and notifications
- Discussions in groups and forums
- Archiving and restoring courses and course materials

The basic goal, and at the same time the main drawback of LMS is their course-centered approach [6]. With LMS, learning and teaching will be oriented along classes, courses, and schedules. LMS are reflecting this strongly organizational and technical perspective on learning in educational institutions.

2.2 School Management Systems (SMS)

As more digital teaching support found its way into schools and universities, it showed that identity and role management have to be refined and separated from LMS and other application platforms. So-called *School Management Systems (SMS)* played this role with typical functions:

- Creating and managing user profiles for authorization, ownership and rights management
- Single sign-on for several learning applications
- Admission management
- Management of exams, assessments, grades, and academic progression
- Monitoring rewards, scholarships, qualifications, certificates, and graduations
- Attendance and activity logs

SMS can be seen as a necessary part of learning platforms as they provide identity and security functions. Seen from a user's point of view they will always be noticeable barriers that prevent from "doing things right now". Real pervasive media do not show such barriers. Identities are resting in the learners themselves only disclosed intentionally and security functions have to be embeddings hardly noticeable far outside or before user's activities.

2.3 Learning Content Management Systems (LCMS)

Learning and teaching are always based on media as the means for communication and external representation. We therefore need *Learning Content Management Systems (LCMS)* to support and reflect the content of didactic methods:

- Upload, download, and management of contents (assets)
- Support for different media types (e.g. Documents, presentations, images, videos, 3d objects)
- Authoring tools for the different media types
- Digital rights management (drm)
- Search functionalities in active storage and archives
- Markup of media for search purposes

LMCS have been built in various ways often tightly connected to certain technological solutions, platforms, or operating systems.

2.4 Virtual Learning Environments (VLE)

As an independent development to the learning platforms already outlined, *Virtual Learning Environments (VLE)* emerged. Sometimes VLE has been used just as a synonym to digital learning environments. In other cases they were seen as an approach to design surrogate learning environments in shape of Virtual Realities that enable learners diving into an artificial, often 3D world with their avatars. For learning, these artificial worlds typically provided functions like

- Avatars as reflections and representations of the learners
- Virtual class rooms, meeting spaces, or labs
- Virtual libraries, some even with anachronistic book shelves and virtual books
- Special environments like virtual labs to learn certain topics or abilities

Some VLEs have strong immersive effects drawing the learners into worlds of imagery with or without natural properties like gravitation, distances, or providing supernatural properties like teleportation, size and shape changing to bring the learners into environments that cannot be experienced in the physical world. Modes and levels of immersion have been discussed by Sherman and Craig [7].

The question is what the roles and effects of current teaching and learning platforms as discussed above, have been for learning processes ([3], [6]). They provide basically access, progress control, as well as asset management in the classical sense of computer use. Only Immersive VLEs try to go beyond this old office work paradigm. They try to let the computer vanish in favor of a virtual world, where the interaction takes place. However, virtual worlds are not connecting the learners with their senses to their real world environments.

3 LEARNING ENVIRONMENTS BEYOND THE CLASSICAL COMPUTER

As discussed above, the computer applications as used in most current learning platforms present themselves as tools or pieces of technology that often distract from learning. We will discuss the visions of Weiser and Norman who pointed out, that computers shall be ubiquitous, but invisible.

3.1 Ubiquitous Computing

Ubiquitous Computing means having computer functionality available at any place and any time. This needs invisible networks to connect computer devices automatically to servers and other devices. The general availability implies for the users that they should neither need to care about connectivity nor about functionality. These devices and services have to be accessible and they have to be cheap for the users. Low availability and high costs are always obstacles for general use. However, serious challenges about identity and security need to be solved. Ubiquitous computers can be seen as a menace to privacy. So for the moment let us imagine, at least conceptually, a world of a safe usage of powerful computer through open networks anytime and anyplace. We have come very close to this situation in the recent years and it can be expected that people will perceive computing power will just be there when they need it, even if there are some critical issues left.

3.2 Pervasive Computing

The general availability of computing devices implies that their functionalities and data have to fit together. However, there is a strong development ongoing through the last decades to make sure, that computing devices for the masses will be interoperating concerning hardware, software functions, and data. Today we can more and more see larger screens, tablets, smartphones, watches, and data glasses working together allowing even *Cross-Device Interaction* between them [8]. This leads to *Pervasive Computing* making computer devices working together without the need for transformational tasks concerning functions or data performed by the users themselves. Ubiquitous and Pervasive Computing match perfectly in making computers working smoothly together.

3.3 Invisible Computing

Nevertheless, even Ubiquitous and Pervasive Computing does not mean that computer get out of the way opening our view for what we really like to see and do. They are still technical devices that are present and need attention, energy, maintenance, and much more. We will sometimes question their usefulness because they are consuming our economical and as well our mental resources. *Invisible Computing* is different because computers are there, but not in the way and not asking for anything without an explainable reason. They will be embedded in our physical contexts, in the surrounding objects, or even with ourselves as mobiles, wearable or implants. Today, many suggestively say that computers will meet our expectations, be smart, and even intelligent [9]. Physical invisibility is not necessarily needed; it much more is a just a result of our mental model of the world around us.

3.4 Ambient Computing

If we combine the concepts of Ubiquitous, Pervasive, and Invisible Computing we will talk of *Ambient Computing*, computer system embedded in our physical world supporting whatever we like to do right now. As discussed above, it will not and does not need to be perfect, but we like to feel the flow of activities as a good experience. Computers will be somehow there, but will not stand between the users, their environments, and their activities. We will discuss why Ambient Computing can be an educational concept for something that we will call *Ambient Learning Environments (ALE).*

4 AMBIENT LEARNING ENVIRONMENTS

Ambient Learning Environments in the sense above need to be simple to use, versatile, and open for new educational challenges, approaches, and topics. Looking back into the history of computing, this often has been characterized by developing computer applications with a low threshold (or floor), wide walls, and high (or no) ceiling, with the initial metaphor coined by Seymour Papert and extended by Mitchel Resnick in the context of programming environments for children [10]. Other approaches in educational circumscribed these aspects as *Universal Design for Learning (UDL)* [11]. We will discuss how this can be translated into learning environments.

4.1 Low Threshold

Computer systems are increasingly complex by their technological nature. This complexity has to be faced by the developers, but not necessarily by the users of computer systems. The field of *Usability Engineering* has been dedicated to this challenge. Among other criteria, the usability of computer applications has been defined by ISO 9241-110 through the seven *Dialogue Principles:*

1. Suitability for the task
2. Self-descriptiveness
3. Controllability
4. Conformity with user expectations
5. Error tolerance
6. Suitability for individualization
7. Suitability for learning

Each of these formally highly independent criteria will contribute to something like *ease of use.* However, we have to keep in mind that these qualities mainly stem from experiences with office systems and similar task-oriented platforms. Environments for learning may be different without making them more difficult to use. For example, computer games do not need to be self-descriptive or conform to expectations, but they need to be motivating and draw the attention of the learners. Learning applications may even break usability rules to be more interesting [12]. It may be a welcome feature, if they create some additional effort to reach a certain goal. For this reason we have to add some concepts from the area of *Experience Design* or its derivate *UX Design,* like aesthetics, storytelling, or mixing virtual and physical spaces to Mixed Realities [13]. Whatever we do, we need attractive and easy to go pathways into the systems especially for beginners to prevent from giving up before they can reach first experiences of success.

4.2 Wide Walls

Learners are “growing”. They may start with some basic capabilities, knowledge, and curiosity to change steadily by growing inside their environment. Growing inside a static environment will result into spaces that will feel like being narrow and too small to keep on growing. If we provide an environment with a low threshold, we will help users to enter it easily. When they are inside, they will be ready to learn using additional functions and actions for certain purposes. This results into some requirements for learning environments to keep the users from noticing walls of learning:

- Important core applications to start with
- Alternatives for interaction, like commands and scripts additional to direct manipulation
- Sand boxes to try out things without the risk of damaging anything
- Becoming more efficient by choosing other paths to solutions
- New applications for new goals and tasks
- Individualizing applications to make them feel more personal and more appropriate
- Constructing new complex functional and data structures out of simple ones

Environments with wide walls are more or less open systems with variations in user interfaces, functionalities, and other qualities that support learners to get faster and better, i.e. to grow. Growing in this sense is learning to apply available knowledge to neighboring or new domains. It is about refinement of available competences, gaining efficiency, and improving the scaffold of learning.

4.3 High Ceiling

Growth cannot not only to be seen in a horizontal way to extend capabilities. Sometimes growth means to change levels. In educational systems we can understand this vertical growth like

- Changing levels of abstraction
- Using metatools to create new tools
- Critical discourses questioning and changing already acquired and accepted knowledge
- Using inference methods to create new out of existing knowledge
- Applying heuristics to understand and cope with complexity
- Deconstructing domains to reconstruct and improve

Educational systems with no or high ceiling are important for long-term learning, creating new perspectives and increasing the cognitive distance to what we do.

5 AMBIENT LEARNING SPACES (ALS)

Ambient Learning Environments (ALE) with the features discussed above are not generally available today. In Section 2 we described several types of educational platforms. However, LMS, SMS, and LCMS are classical technology-centered computer applications derived from office systems. Only VLEs are sometimes solutions that try to hide the computer behind the curtain of virtual worlds with even the users themselves replaced by avatars or other virtual constructions like hands or shapes. The main drawback of VLEs is the strong separation of the learners from authentic physical learning contexts. Concerning the content, VLEs usually do not provide a knowledge representation level.

To study the potential of ALEs, as proposed, we designed and implemented a pilot system for daily operation in schools and museums. We called it *Ambient Learning Spaces* or short *ALS* ([3], [14], [15], [16], [17]).

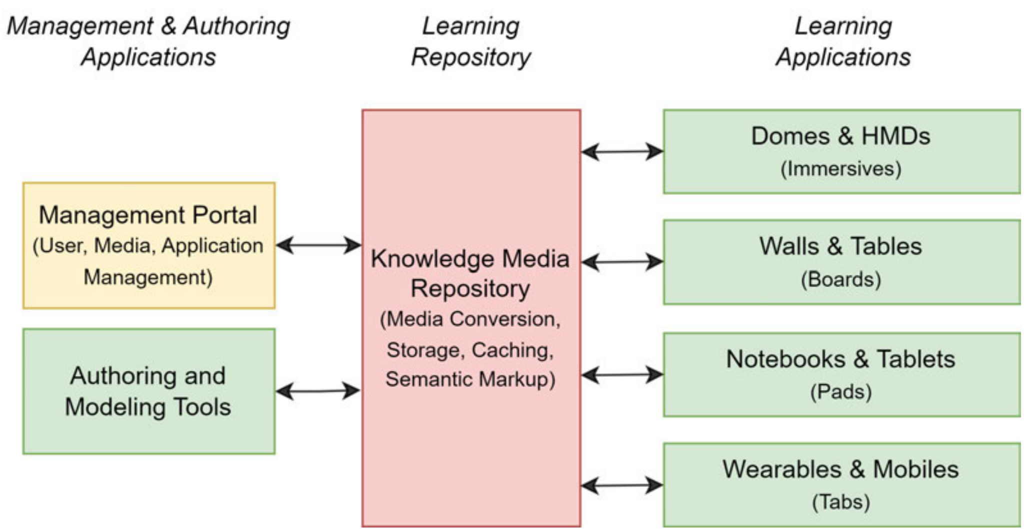

Figure 1. ALS as a generic Ambient Learning Environment (ALE) Architecture

5.1 A Generic Architecture for Ambient Learning Environments

ALS is an infrastructure providing modularized frontend learning applications *(ALS Modules)* for mobile, stationary, and immersive interaction. To create a pervasive experience of integrated seamless media, ALS has been based on a central backend system, the *Network Environment for Multimedia Objects (NEMO)* [18]. The ALS Modules are connected to *NEMO* which provides, besides several services, the semantically annotated structured learning media. The basic system architecture of ALS can be found in Figure 1. The applications are decoupled from the backend by web-services. Most of the frontend applications and authoring systems [19] are web-based for maximum flexibility in current standard networks. The NEMO repository can be installed and operated at any place, only depending on internet access and sufficient bandwidth for the volume of media stored and used.

5.2 ALS Wearables and Mobiles (Tabs)

Authentic education through social activities in context is a constructivist approach to build individual knowledge. Learners leave artificial learning environments and enter live spaces like urban, industrial, and natural environments or places of collections like museums or archives. With mobile applications on smartphones, tablets, or wearables, the computing devices are with the learners in the sense of BYOD [20]. The learners carry the scaffold of teaching and learning with them, study in real contexts, and collect data and media to be brought or transmitted automatically to the central backend (NEMO).

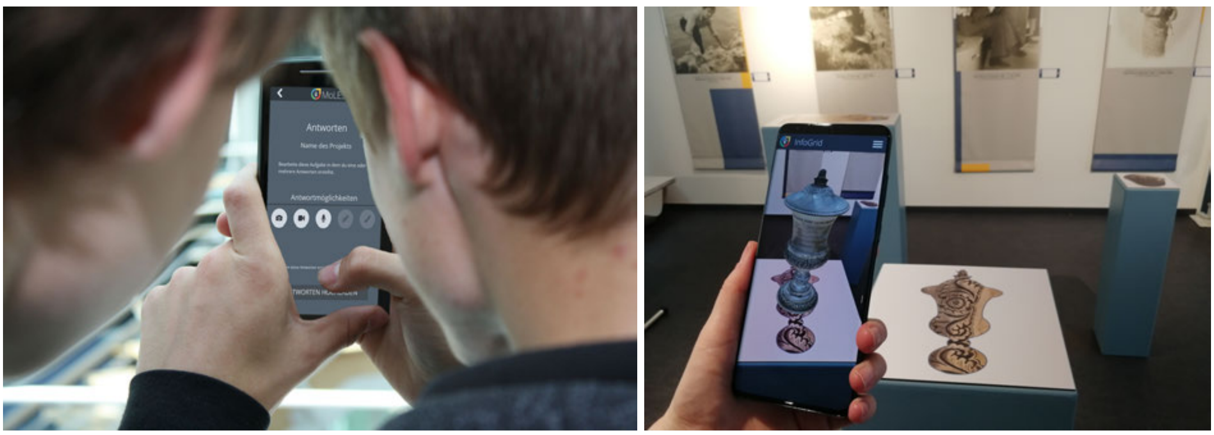

Figure 2. ALS Mobiles (left: MoLES, right: InfoGrid)

The ALS mobile app *MoLES (Mobile Learning Exploration System)* provides a task-based framework to guide learners through a series of tasks and challenges along a physical and logical learning path, the *tour* ([20], [21]) (Fig. 2 left). Learners search and store data about the objects and contexts and follow the next task until the whole tour has been completed. MoLES stores or transmits data and media to NEMO. It can be seen as a discovery and serious game approach, which has been applied to a broad spectrum of authentic learning situations.

InfoGrid, an *Augmented Reality (AR)* mobile app enables studying a physical environment by searching active objects (targets) ([20], [22]) (Fig. 2 right). For any target it will be activating visual or auditory overlays like images, audio and video clips, or static/animated 3D models. The learners visit certain places and point their smartphone or tablet cameras towards the targets like physical objects like houses in a city or artifacts in a museum. InfoGrid is able to display a map or a floor plan to guide the learners through the environment. We found that even school students in secondary schools were able to create their own AR tours for themselves or other students [23].

5.3 ALS Stationaries and Tangibles (Pads and Boards)

In many cases learning will be happen in social processes in community or group spaces. In ALS we developed large multitouch screen frameworks with applications like the *InteractiveWall (IW)* (Fig. 3) ([24], [25]). Besides the IW there is an *InteractiveTable (IT)* to support certain spatial setups. Additionally to the IW, the IT will allow the use of *tangibles (fiducials),* i.e. physical objects that can be placed on the IT to interact with the applications, for example for tagging or filtering. IW and IT layouts can be defined by users themselves to create their own social presentation and interaction spaces.

Figure 3. ALS Interactive Wall in schools and museums
(left: Carl-Jacob-Burckhardt-Gymnasium, right: Buddenbrookhaus Museum, Lübeck, Germany)

The IW provides the *MediaGallery* module that gives access to collections of static preselected media or dynamic collections semantically bound to objects of the learning domain through tags.

TimeLine is an ALS module that displays a time axis visualizing knowledge entities with chronological meaning and dependencies (events) (Fig. 4 left) ([26], [27]). Events represent a point or a period of time on the chronological graph and can be annotated. TimeLines can be “filled” with media like text, image, audio, or video from the central media repository. Users can navigate by touch interaction through the chronological graph and explore knowledge entities with annotated content. A TimeLine display consists of one or more sub-timelines above one time axis, i.e. semantic dimensions over the same period of time. This allows multiple perspectives on history and helps to identify, question, and explain causalities and other dependencies in the topical domain.

SemCor is a learning application for active search and knowledge creation using an IW [26]. It allows interactive exploration of semantic correlations between media-enriched knowledge entities in a *semantic web*. One can use a starting seed to explore semantic correlations from there. SemCor connects to semantic repositories (e.g. DBpedia, Europena) to search for related entities. Once related entities are found, they are grouped into categories and are visualized in a force-directed graph (Fig. 4 right). Entities can be selected to further expand the visualized knowledge space. After selecting a knowledge entity, further detailed content (e.g. a Wikipedia article) is shown and can be explored. SemCor will automatically and dynamically deliver new knowledge entities in the graph through certain search algorithms and filters. SemCor resembles and visualizes the mesh and the complexity of world knowledge and motivates explorations through the serendipity phenomenon.

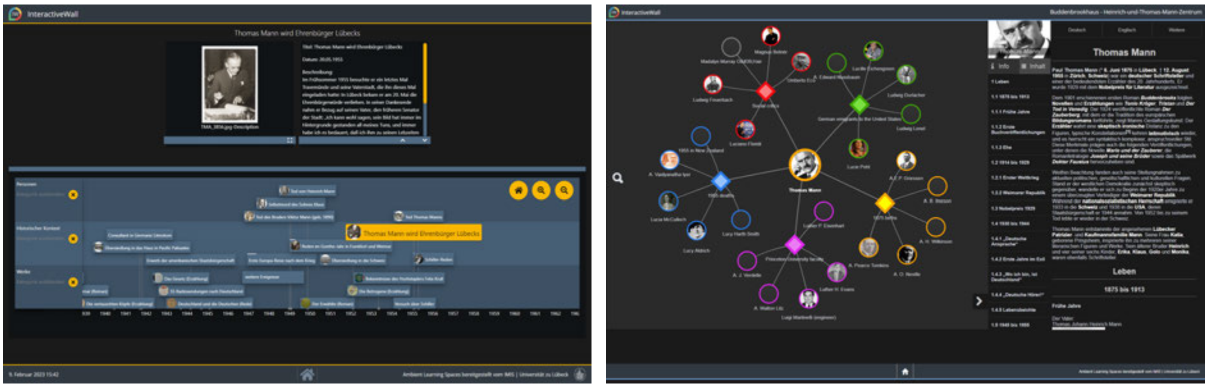

Figure 4. Semantic ALS Board Applications (left: TimeLine, right: SemCor)
Buddenbrookhaus Museum (Heinrich-und-Thomas-Mann-Zentrum), Lübeck, Germany

5.4 ALS Immersive Media (Immersives)

Special properties come with immersive media. Actually, they are more a result of human perception than a certain kind of technology. Sherman and Craig [7] distinguish *physical* and *mental immersion* besides *immersion* in general. We will mainly refer to physical immersion when we discuss immersive media in the context of ALS [28]. Most of the ALS modules discussed above can be adapted and included in immersive environments. This transformation through editing, morphing, mapping, embedding, and linking media into immersive forms can be an active design process performed by learners themselves. The more immersive applications will be available, the more a *Mixed Reality Learning Environment* will be created [29]. The media currently in use in ALS for immersive applications are mainly 360° images and videos. Both can be enriched by interactive elements, like in the ALS *HyperVid* module [30], to create non-linear 360° hypervideo narratives with interactive buttons to switch content. As presentation and interaction technologies we used VR HUDs like Oculus Rift and Oculus Go as well as full dome presentations. Rectangular 360° images and videos can be transformed into HUD and dome formats (e.g. fisheye views) to create strong immersive effects. Another technology that has been used for immersive presentation and interaction are VR players for Web VR solutions like A-Frame. The *InteractiveDome* in one of the schools gives place up to 15 students or teachers (Fig. 5). The VR mode supports the interaction with 3D objects that can also be created by students themselves through a photogrammetric pipeline from images and video footage [31].

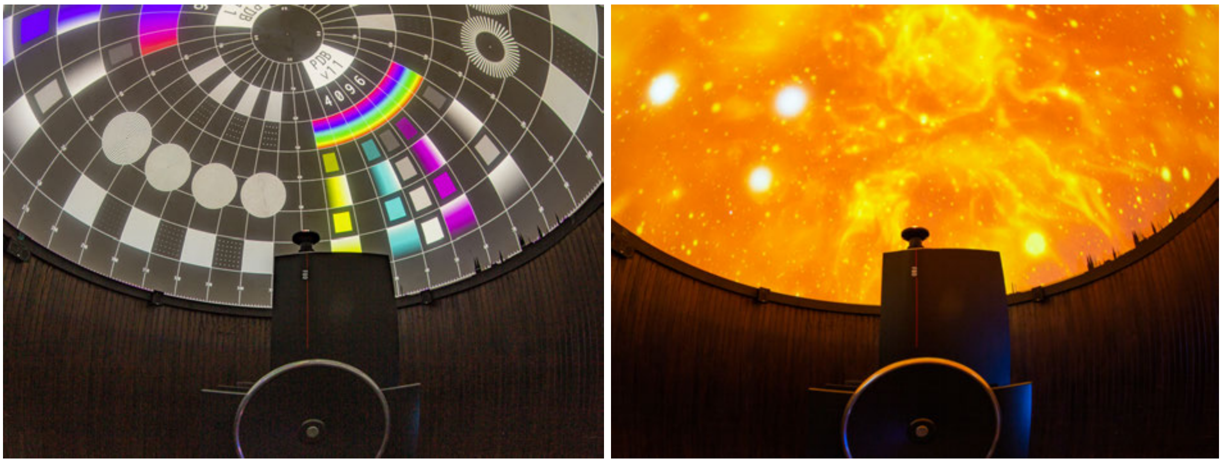

Figure 5. ALS InteractiveDome in the historical planetarium "Sternkammer"
Grund- und Gemeinschaftsschule St. Jürgen, Lübeck, Germany (© images by Ralph Heinsohn)

5.5 ALS Qualities as an Ambient Learning Environment

ALS shows qualities of an ALE with low threshold, wide walls, and high ceiling as discussed above.

5.5.1 *The Modularity of ALS*

During the development of ALS many learning applications have been build. After having developed the first of them, it showed that it would be helpful to have common backend storage for user data, media and media converters, application logic and storylines. Besides the learning application modules like *MediaGallery, TimeLine, SemCor, MoLES,* or *InfoGrid,* the need for authoring media and other content emerged. As a result, several authoring modules like *ImageEdit, VideoEdit,* and *3DEdit* have been developed. An important requirement was the tight integration of these authoring tools into the environment to make it easy to create and change media without leaving the learning applications. To prevent from installation and licensing issues the authoring systems have been developed as web-based systems [19]. After developing generic web service and storage interfaces, device-oriented media transformation functions and caching mechanisms, it was easy to add new learning modules and editors to ALS. The modularity of ALS is the foundation for *wide walls*.

5.5.2 *The Usability of ALS*

To make sure that ALS will not impose disturbing *thresholds,* it has been designed in *participatory human-centered development processes* together with schools and museums. The functionalities and user interfaces of the applications have been developed collaboratively with teams from both institutions. After initial prototyping the applications have undergone many iterations of improvement through operational tests and evaluations. Especially the change from stand-alone to modularized applications connected to the central backend NEMO made the learning applications more similar in their design and their many common functions like the access to the media and the authoring tools.

5.5.3 *The Knowledge Level of ALS*

In the beginning, ALS has been designed as a multimedia environment. The main representations and the storage layer were handling plain media types. As more learning applications had been added, it showed that a knowledge representation layer would be helpful to enrich media with semantics. As a first approach *tagging* had been used. However, personal tags are often semantically similar, but syntactically different. Therefore it was clear that especially for professional applications like in museums it would be helpful to use pre-defined *thesauri*. Stronger representation mechanisms in *TimeLine* and *SemCor* motivated to use *classification mechanisms* like classes and instances. This leads to higher knowledge management functions like forms of *automatic inferences* based on production rules or logic terms. The knowledge representation mechanisms have not been implemented completely through all ALS modules. This would be a consequent next step to make ALS a consistent knowledge-based media environment leading to a *high ceiling* for different kinds of knowledge representation and machine intelligence [5].

6 SUMMARY AND CONCLUSIONS

Ambient Learning Spaces (ALS) is an integrated multimedia platform. As a result of its high usability qualities it is easy to use with a low threshold for teaching and learning. Based on a central data and media storage it allows to construct and share media across a variety of interactive learning applications like wearables and mobiles, interactive walls and tables, as well as immersives like head-mounted displays and full domes. These various applications in different forms and sizes empower in the sense of wide walls to adapt to any learning context inside and outside schools. A high ceiling stems from knowledge representation on different levels from semantic tags, through the use of thesauri, reaching to classifications and inference methods. ALS has been used in several pilot installations in schools and museums and has been evaluated for its usability and pedagogical values. The results show that teachers and learners were enabled to use the different modules of the ALS system for teaching and learning in different ages, topics, and levels of abstraction. ALS can be used as an architectural blueprint for new generations of Ambient Learning Environments (ALE) with low threshold, wide walls, and high ceiling for active and self-directed learning.

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