AMBIENT LEARNING SPACES FOR SCHOOL EDUCATION

M. Herczeg, T. Winkler, A. Ohlei

University of Lübeck (GERMANY)

Abstract

The contribution presents a system concept for digital teaching and learning environments, which includes current media concepts and enables a pedagogy that is only possible through the use of new digital interactive media. The concepts for this learning environment have been based on contemporary pedagogical theories in awareness that learning processes are going to be less dependent on teaching technologies and content and more on active processes of learning itself. A platform and environment called Ambient Learning Spaces (ALS) has been developed in a series of research projects, which enables individuals as well as groups of learners to create, share, distribute, and reuse semantically annotated media in a social teaching and learning process. The Network Environment for Multimedia Objects (NEMO) forms the technological backend for different ALS frontend learning applications. It contains a semantically modelled, cloud-based repository for rich media applications and allows the creation of semantically annotated multimedia content to be used across these applications. These applications can be used on mobile or stationary interactive systems such as domes, large screens, tangibles, mobiles, and wearables. The media like text, image, video, or 3D can be reused in the different learning applications and will be adapted automatically for various interaction devices with different media capabilities. Interaction methods depending on the available devices reach from direct manipulation interfaces on touch displays to augmented reality or 360° interactive virtual reality applications. In the ALS-Portal, learners include and edit their own media and annotate them semi-automatically. Teachers select and manage the learning applications and prepare the teaching content and logic for their pedagogical purposes. The learning applications support both stationary and mobile learning, all based on NEMO and its semantic media repository. Special user interfaces like tangible media and large multitouch screens as well as mobile media and wearables enable body- and space-related learning in real life contexts inside and outside of school. Based on pedagogical approaches and requirements, the contribution describes the structure and function of the platform and gives an overview of the different learning applications together with evaluation results. Besides the school context, ALS has been used in museums.

Keywords: Ambient Learning Spaces, Learning Environments, Learning Spaces, Ambient Learning, Multimedia, Expansive Learning.

1 INTRODUCTION

We will discuss a new system concept for digitally enabled teaching and learning environments that include already existing media concepts and enables a pedagogy that is only possible through the ubiquitous dynamic new digital media. Our basic concepts for the *Ambient Learning Spaces (ALS)* environment have been based on contemporary, well recognized pedagogical theories, such as those described in *Assisted Learning* by Arnold [1] or *Expansive Learning* by Engeström [2] clarifying that learning processes are less and less dependent on teaching content and more on the active process of learning itself. Together with the notion of a ubiquitous and pervasive digital environment, as discussed by Weiser [3], self-driven and creative learning supported by such a digitally enriched, ubiquitous learning environment has a high potential for future education. Technical, methodological, and social competencies need to be considered together as they influence the individual development of learners to a high degree. We have to think about a learning culture that favors forms of self-organized and self-directed learning using ubiquitous digital extensions of ourselves in the sense of McLuhan's *Extensions of [Hu]Man* [4]. Learning has to be oriented towards a living learning process in which the learner discover and construct new and different knowledge structures and content. Even in highly digital and therefore increasingly virtual environments, joint learning and references to the real world are important for grounding and progress.

2 METHODOLOGY

ALS is based on several methodological foundations. In this section we will reference some of the more important pedagogical theories as well as the resulting systemic model of ALS.

ISBN: 978-84-09-14755-7

2.1 Pedagogical Foundations of Ambient Learning Spaces

At the end of the 20th century and now in the 21st, pedagogy and didactics mostly follow interactionist-constructivist (e.g., Reich [5]) and systemic-constructivist approaches (e.g., Arnold [1]). Contemporary didactic approaches assume that learning is an active construction process, where a learner creates an individual representation of the world. However, this process is not purely subjective, as early constructivists like Maturana and Varela [6] hypothesized, since each subject is in relationships with other subjects within many communication communities. Via common communication systems any statement about reality is subject to viability, i.e. a change in interests, power possibilities as well as social, economic, cultural, symbolic capital formations in the sense of Bourdieu [7]. Learning thus depends strongly on individual prior knowledge and the social, natural and technical environment in which learning takes place.

Even when we have to question Piaget's rigid step-by-step development model [8] because of the social, societal and cultural influences of learning, Piaget's fundamental approach to learning theory remains groundbreaking: It is not possible to transfer knowledge from one person to another person; instead, each person must construct it by him- or herself depending on his or her previous knowledge and skill level, attitudes and the current learning context. As a result, learning is not passive storage, but active construction of knowledge, which has to be supported by the learning environment. In contemporary constructivist models, the role of a teacher is not to impart knowledge, but to support learners in their individual learning process through a balanced measure of instruction. The learners shall independently deal with the learning content, for example by content selection and discovery of relations between chunks of already available knowledge.

Comparable to the interactionist- and systemic-constructivist approaches, but not as prominent, is the theory of *Expansive Learning* in the sense of Engeström. His pedagogical approaches follow the so-called cultural-historical theory of activity, founded in the 1920s by researchers such as Vygotskij [9] as well as Leont'ev [10] and further differentiated in *Critical Psychology* for *Self-Determined Learning* by Holzkamp, as discussed by Engeström [2]. According to Critical Psychology, learning in general means the appropriation of an object meaning by a learning subject and not the achievement of a normative educational ideal. In addition to concrete things, this also includes abstract and symbolic connections. Thus, Expansive Learning addresses individual or collective learning processes with the goal of extending action possibilities, competencies, and self-determination.

If the design of digital systems supporting learning by following contemporary pedagogical-didactic models as briefly presented above, digital learning systems and environments shall be enabling the individual construction of sustainable knowledge, i.e. knowledge that finds a relevance of use in the reality of daily life. In this case these systems support individual and also cooperative learning by establishing a strong connection to the physical world connected to the human body and the social reality of the learners. In the recent development of interactive multimedia systems, we see a revolution in the design of user interfaces like in peripheral media, tangible media, mobile media or wearables (Fig. 1) embedding the human learner even bodily. Learning software, which uses such capabilities of the new interfaces, has the highest potential to support learning in school contexts, also collaboratively, and, above all, a relevant relationship to life physically and mentally.

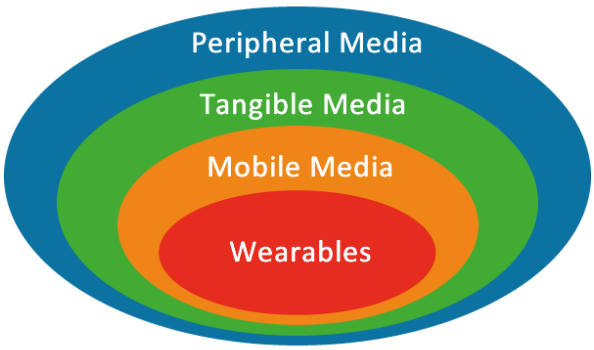

Figure 1. Shell Model of ubiquitous media used in ALS

2.2 A Systemic Media Platform for Contemporary Pedagogy

To enable or support the pedagogical concepts, including especially the teaching of digital media competencies, we developed a systemic technological concept for a digital media platform that can be connected to real world contexts during teaching and learning. The system has been called *Ambient Learning Spaces (ALS)* and has been developed in our human-computer-interaction research institute since 2009 [11]. Media created or provided can be accessed and changed by a variety of modular interactive frontend applications for stationary installations as well as mobile apps and can be reused in different teaching and learning contexts [12]. Therefore this platform can serve as the substrate of digital teaching and learning in and outside the classroom. The access to the media will be performed through different interaction forms, like image and video viewers, interactive textual form filling, dynamic image graphs as well as augmented and virtual realities or wearables.

A technological multimedia platform for teaching and learning needs to support a wide variety of media types like text (documents), video, 2D and 3D graphics, or 360° video. Media created by students or teachers has to be manageable and reusable in other contexts as well. These media shall be enriched by annotations from application contexts. As one special kind of annotation or attributes, the platform allows flexible personal, group and public ownerships based on the social relationships of usage.

Other annotations of the media are formal relationships to higher level concepts as well as informal tagging. The higher level concepts are for example taxonomies referencing DBpedia or self-constructed taxonomies. These formal relationships or informal tags will transform the media into semantic media related to real world contexts. Tags usually stem from ad hoc references during social use. Certain tagging can be done semi-automatically from the context of use itself, like the project ongoing or geographic and chronological references throughout the process of use.

These media need to be hosted and organized in a cloud-based distributed media database. Each medium is built as a structured collection of raw media for different input and output devices. The platform is able to dynamically generate device dependant variations of source media like images, videos or 3D objects with, e.g., specific aspect ratio or resolution as needed. The adaptation of media will be done automatically in cases, where the applications deliver information about the devices used, like mobile smartphones do. A large library of media conversion tools needs to be integrated.

3 THE ALS ARCHITECTURE AND ALS APPLICATIONS

The pedagogical requirements described in the previous section have been translated into the technical ALS system architecture (Fig. 2). The architecture follows a layered approach to ease further development.

The architecture has been structured vertically into an *Application Layer (Mobile and Stationary Apps and ALS Portal)*, a *Service Layer (NEMO API and Services),* and a *Data/Media Management Layer (NEMO Logic and Database)*. The Application Layer contains the frontend systems, which are structured horizontally into interactive modules for teaching and learning (Learning Applications), for management and authoring systems (Authoring Tools with ALS Portal) as well as for the delivery of media to the learner according to didactic algorithms, rules and storylines (Data Delivery). The Service and Data/Media Management Layers represent the cloud-based semantically modeled repository called *Network Environment for Multimedia Objects (NEMO)* [13]. It stores the raw media as well as their higher level descriptions and structures with certain services for media generation, annotation and conversion.

3.1 The ALS Learning and Teaching Applications

The ALS environment provides through its *Application Layer* many different application modules mainly used by the learners and in some cases by the teachers, to initiate and organize the learning process. These software modules can be used to construct and enrich specific learning contexts. However, all of these frontend modules use the same backend system NEMO with the same backend utilities as well as a common storage layer for all multimedia objects generated and used in the learning processes. In the following subsections some of the most important and most far developed modules will be outlined. New modules can be added easily and dynamically to the open ALS platform. The application modules developed and listed in Table 1 fit into the model of media in the shell model depicted in Fig.1.

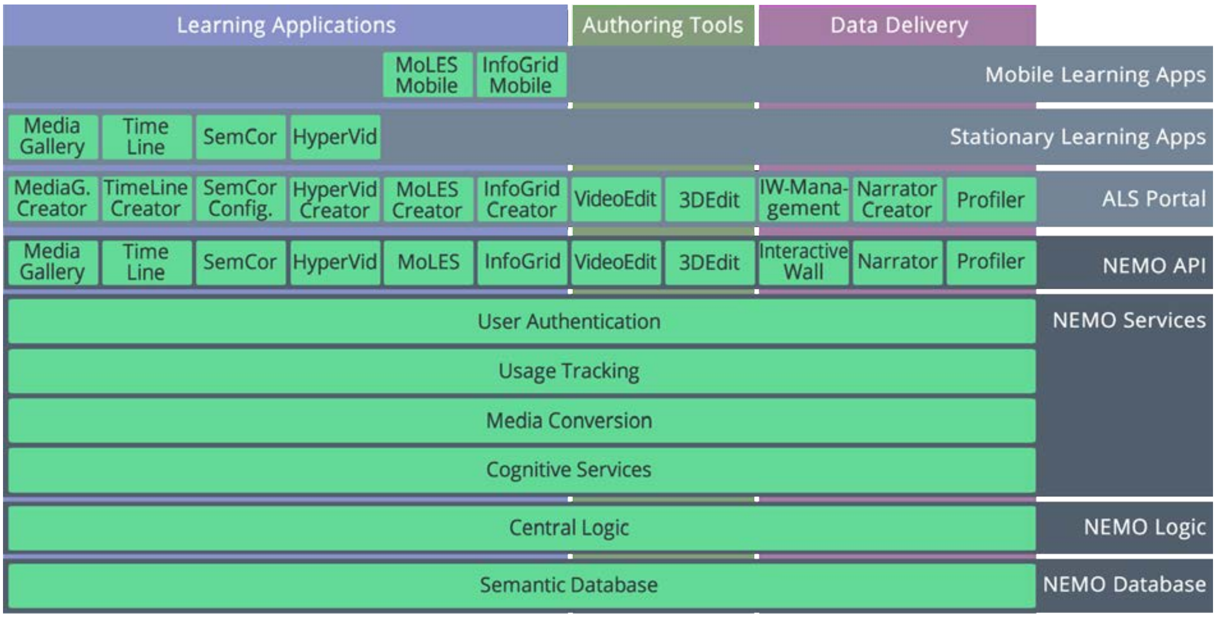

Figure 2. ALS System Architecture

Table 1. Location-based and location-independent media (cf. Fig. 1).

Location-based Media **Dialogical and Interactive Opposite**		**Location-independent Media** **Extended Self**	
Peripheral Media	**Tangible Media**	**Mobile Media**	**Wearables**
Act^e^Motion	***InteractiveWall*** ***MediaGallery*** ***Timeline*** ***SemCor*** ***Hypervid***	***MoLES*** ***InfoGrid***	***Smart Fashion***

3.1.1 *Interactive Wall (IW)*

As an important integrative environment built as a stationary frontend for class rooms or school foyers we implemented a system called the *Interactive Wall (IW)*. The IW is a kind of social entry point for the teachers and learners for cooperative learning [14]. The IW consists of an arbitrary number of large interactive screens that can be installed in buildings and rooms (Fig. 3). They are realized by multiple affordable TV displays with hi-res touch-sensitive frames. They are driven by a distributed array of client computers connected to NEMO. Many of the learning applications can be accessed or controlled through the IW.

Figure 3. The Interactive Wall (IW), as social access point to ALS.

3.1.2 *MediaGallery*

The *MediaGallery* is an application running on the IW. As the IW is providing highly visible public interactive displays, the MediaGallery enables users to explore personal, group-based or public media collections about any learning topic (Fig. 4). Each media gallery consists of a set of images, videos, documents or 3D objects that are either manually combined or defined by a selection based on semantical correlations and search. When multiple media galleries are available, the IW has an option to place several randomly dynamic previews of public media galleries on the main screen. Media galleries collect, display and separate contents. They represent ownership as well as common ground.

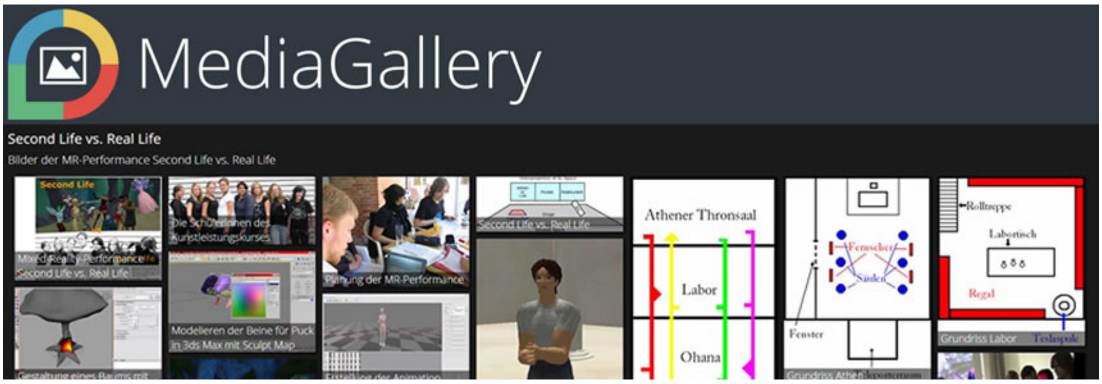

Figure 4: MediaGallery, for media collections of student projects.

3.1.3 *TimeLine*

TimeLine is another learning application usually running on public screens of an IW. It presents a multidimensional visual structure to do research on historical events on several time threads (Fig. 5). Users can use swipe gestures to go back and forth in time at low or high speed on a linear or logarithmic scale. Filters simplify the access to the most interesting content. Each entry on the TimeLine can contain media files such as text, photographs, or video clips. To analyse entries inside the TimeLine in depth, elements can be further explored in other modules like SemCor (see next subsection). From a pedagogical point of view the TimeLine shows chronological correlates in several parallel time threads.

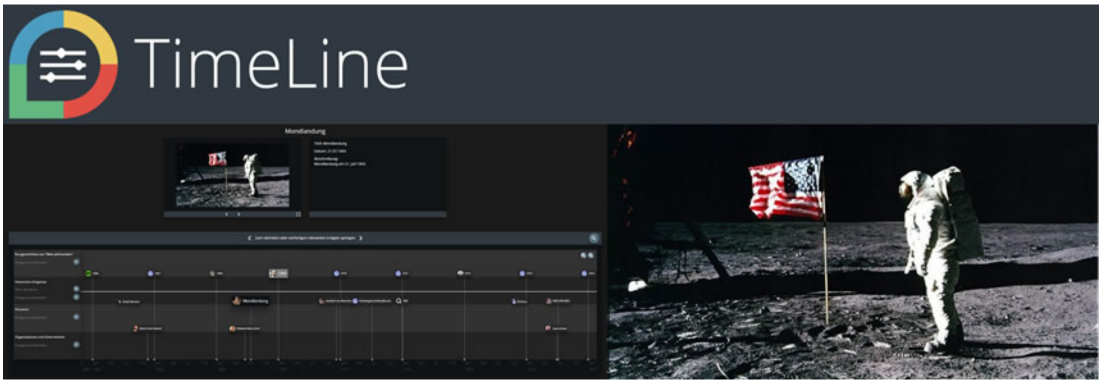

Figure 5: TimeLine, to interact with chronological knowledge.

3.1.4 *SemCor*

SemCor (Semantic Correlation) is another application available on the IW. Users explore information elements along semantic relationships provided by the worldwide DBpedia database. Ontologies are delivering a small universe of knowledge chunks related to each other in a mesh (Fig. 6). While being used, the system is constantly searching the world – actually the web – for new relations and entities related to the already displayed and selected ones. Different algorithms to calculate similarity of such entities help to choose from a large amount of candidates found to be displayed. SemCor supports associative learning based on *serendipity* and *curiosity*.

Figure 6: SemCor, to interact with semantic relationship between knowledge entities.

3.1.5 MoLES

MoLES is a web application for smartphones and tablets to support task-oriented teaching mainly outside school for example in urban space, natural biotopes or museums (Fig. 7). Teachers or older students can define tasks to be solved within project-oriented teaching [15]. The students will face tasks like challenges to be solved outside school. While following the tasks and orders they collect and bring back media captured with their mobiles. These media will automatically be uploaded into the NEMO system to be available for further use like a documentation of results in a project media gallery.

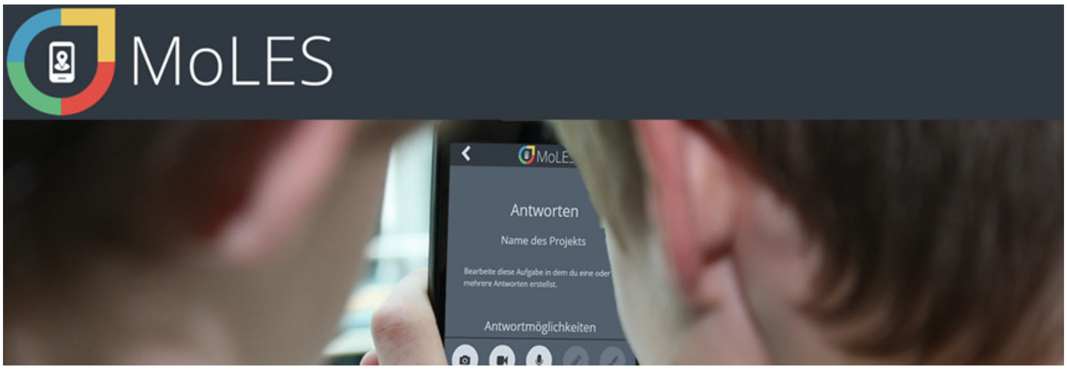

Figure 7: MoLES, a mobile task-oriented system.

3.1.6 InfoGrid

InfoGrid is a learning app that uses *Augmented Reality (AR)* technology to display personalized and contextualized information such as images, videos, interactive 3D objects as virtual overlays for physical space (Fig. 8) ([16], [17]). Users can use the app in places, where the image targets that trigger the augmentations have been placed. When the app is started, it shows the physical environment on the screen of the device along with the overlaid virtual information. Students can for instance use InfoGrid to create augmented posters for their projects, to set up exhibitions or to create interesting AR games inside or outside school. InfoGrid runs on Android and iOS mobile devices.

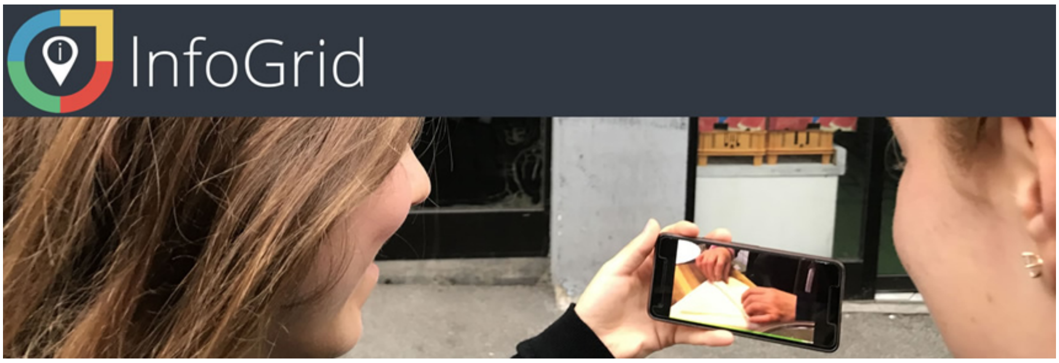

Figure 8: InfoGrid, a mobile AR and storytelling system.

3.2 The ALS Portal and Authoring Systems

For a learner-centered self-driven learning process it is a basic requirement that students and teachers themselves shall be capable of creating and annotating media as well as managing the platform by defining users or by activating or deactivating certain application modules. This resulted in a management module we call the *ALS-Portal*. The need to create, edit and manage media resulted in several easy to use *authoring tools* for images, video, and 3D capture or the placement of virtual objects in physical settings for augmented reality applications.

3.2.1 ALS-Portal

The *ALS-Portal* can be used to create and edit information for all ALS learning applications and allows activating or deactivating these applications. Users can access the ALS-Portal through a regular web browser or the Interactive Wall. After logging into the ALS-Portal it presents a list of ALS applications that are available for his or her user account (Fig. 9). The user can then begin create or edit information. All data entered through the ALS-Portal will be stored inside the NEMO backend.

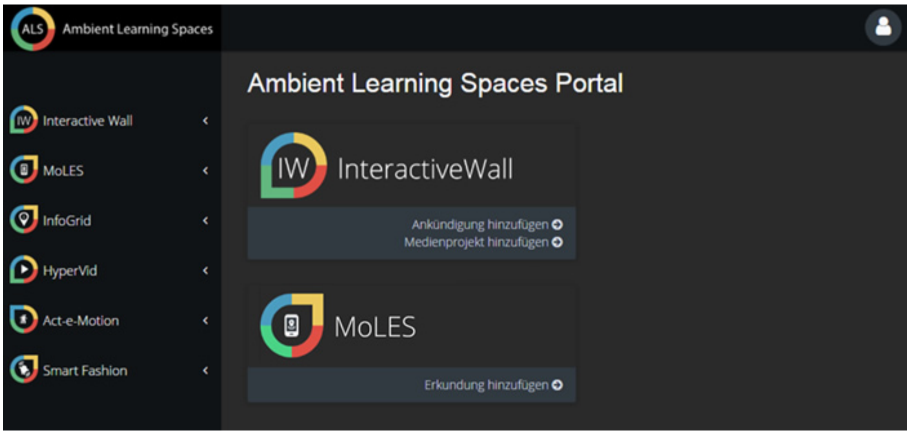

Figure 9: ALS Portal for the management of the ALS applications and content.

3.2.2 VideoEdit

VideoEdit is a web-based tool that can be used to create and edit video footage. Users can upload their media files such as images and videos either through their mobile phones or through a local computer. These media files can then be merged into a new video file. VideoEdit supports adding a separate audio track as well as a text overlay track and has important additional functions such as increasing and decreasing the volume of the resulting video. After preparing the video in the frontend, NEMO renders the video using the FFMPEG framework. The resulting mp4 file is automatically made available for all ALS applications.

3.2.3 3DEdit

We implemented a special functionality for the generation of 3D objects from 2D photographic footage [18]. This has especially been used to generate 3D models for augmented or virtual reality applications. After creating a 3D object using the *3D Object Converter*, the resulting objects usually contain unwanted artefacts and are randomly placed in space. 3DEdit can then be used within the web-based ALS portal to cut and delete the unwanted artefacts from the 3D-Object and to correct the position, scale and orientation in space. After finishing this process, the 3D objects can be used in other ALS applications such as the MediaGallery or InfoGrid [19].

3.2.4 Narrator

With the web-based *Narrator* module inside the ALS Portal it is possible to create storylines for ALS applications. The user can create and annotate story elements with semantic information in a way that the NEMO framework can create relations between the elements. To experience the created storylines, the InfoGrid AR application can be used for example, where the user will be guided according to the storyline. The Narrator will guide the user depending on their interests, earlier visits or topics of interest along a path of activities. The dramaturgical structure can be created based on some historic models for storylines like models from Aristotle or contemporary ones.

3.2.5 Profiling and Personalization

All media stored in NEMO using the ALS Portal can be semantically annotated during the creation and uploading process. Besides topical areas, the annotation can also include information about the language used within the media or the recommended age of the target users. Using the profiling and personalization service all ALS applications can select the appropriate data for the user. The NEMO framework also includes a converter service so that all media elements are converted into the correct format depending on the currently used device that requests the information.

3.3 The ALS Services

The ALS architecture contains a *Service Layer* to support application modules with several services.

3.3.1 User Authentication

The Administrator of the ALS Portal can setup institutions and assign teacher accounts of a specific institution. With their accounts the teachers themselves can then create and edit accounts for the students. The teachers can also define student work or project groups. Depending on the ALS application the teacher has the function of a moderator with rights to publish and unpublish information for public display or reuse entered by the school students.

3.3.2 Tracking

The NEMO framework includes a *Tracking Module* that can be used to anonymously log and track user requests from all ALS applications. To inspect the tracking data the ALS Portal contains a tracking visualization module. This supports insights on preferences and possible problems. It shows statistics of applications used or media queries indicating how often media files are requested.

3.3.3 2D/3D Conversion

The *NEMO 3D Object Converter* can be used to automatically create 3D models out of a series of photographs taken of a physical object [18]. The user can upload photos into the object converter, which then automatically processes all files using photometry methods. After completing the process, the object converter outputs an .obj file stored in NEMO.

3.3.4 Cognitive Services

When the ALS portal is used to upload media files into NEMO for any ALS application, it is necessary to provide semantic tags. To simplify and speed up the process of tagging, the *Cognitive Services* analyse the selected media and provide suggestions for the user. The user can accept or reject the suggestions for tagging. The Cognitive Services layer uses AI-based methods.

3.4 The ALS Logic and Database

The backend of the ALS architecture is represented by a *Logic and Database Layer* to provide persistent semantic storage of media.

3.4.1 Central Logic

The ALS Central Logic of NEMO contains the mechanisms to store and retrieve media content depending on the applications and frontend devices as well as ownerships of media. It connects the NEMO Services with the database.

3.4.2 Semantic Database

NEMO makes use of a Semantic Database to store information in a semantic RDF information model. The Open Source BrightstarDB has been used for the implementation. The SPARQL query language can be applied by the Central Logic to access content in the database.

3.4.3 Cloud-based Networking

NEMO can be hosted on any physical or virtual machine in a network. Several NEMO instances may be connected and layered to provide content independent of its current location. NEMO can be viewed as a distributed cloud-based storage system of semantic teaching and learning content to serve any frontend environment and satisfy ownership, digital rights and security needs.

4 EVALUATION STUDIES AND RESULTS

During the last years the ALS Framework and its applications have been evaluated in many different dimensions and criteria in the lab, in museums as well as inside and outside school.

4.1 Pedagogical Models and Studies

The usage of the ALS System in school teaching has always been accompanied by studies. Apart from different qualitative surveys, student's activities on the IW are tracked via NEMO providing detailed statistical data. By these tools we can check the frequency of usage of the applications, the access of the media themselves as well as the media volumes created over time. This allows discussing the practical values of the applications in respect to their pedagogical relevance.

It can be summarized at the time being, that the ALS applications have be used by several hundred teachers in about 20 different schools on different class levels so far to construct their own understanding of the digital transformation of school teaching. Each of the teachers has his or her own didactic methods and pedagogical values. It would be of no use to evaluate the ALS environment pedagogically as one system independent of the special needs, constructs and contexts of usage. However the modules have proved to be usable in a variety of teaching contexts over school terms. To prepare for the teaching, we have been providing many seminars for teachers over years to train the use of the applications technically as well as didactically through the German Institute for Quality Development at Schools Schleswig-Holstein (IQSH).

4.2 Usability and User Experience

The frontend applications have been developed in user-centered development processes under participation of teachers and students. Most of them have been evaluated for their usability with SUS or ISONORM questionnaires. The formative evaluation results have been used to improve the usability through many development cycles. Most of the applications show a high level of usability. However, there are always new apps, which are still in an early stage of development and evaluation.

4.3 Technical Validation and Performance

The ALS Environment has been implemented as a layered .NET-based architecture, which supports agile development. Most applications have been programmed in C#. The database has been build with BrightstarDB. Frontends have been implemented mostly for web browsers in HTML5 and CSS3 or as native apps for iOS and Android.

The ALS System is a large hardware and software system that has been tested in many ways to deliver the performance that is needed in the teaching settings discussed inside and outside school. The current system is able to host many teaching projects over years in schools and museums with thousands of media elements stored and managed. As a result of the database concept with a separation of structural information and large media objects, the system is highly scalable in volume.

ALS is a continuously running environment that is currently used on a daily basis by several schools and museums. However, it is still a prototypical research environment with a limited operational dimension.

5 CONCLUSIONS

Ambient Learning Spaces (ALS) is a prototypical teaching and learning environment for a wide variety of learning contexts at school. They are based on contemporary learning theories like Assisted or Expansive Learning bringing the learners into an active role. A semantic media repository allows the reuse of media in different context and for different interaction devices. A large spectrum of modular learning applications for stationary as well as mobile learning has been build, applied and evaluated in real teaching contexts. The usability and pedagogical studies show that the ALS applications can be used effectively and efficiently by students and teachers. ALS support body- and space-related learning by providing a large variety of frontend systems from wearables through mobiles to room-based installations. The applications are modular and the media reusable to enable the teachers to adapt and reuse the ALS system and their content according to their teaching requirements. ALS are ubiquitous and pervasive and do not imply or force their own didactical methods. ALS is currently piloted for two schools and museums but has been made available to a larger number of institutions, who tried out the application and authoring modules in their teaching over several years.

ACKNOWLEDGEMENTS

We develop the system described in the ongoing research project “Ambient Learning Spaces” supported from 2009–2020 by the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG). We also thank our school and museum project partners for their continuous support and their permission to do our field research any time within and together with their institutions.

REFERENCES

[1] R. Arnold, *“Assisted Learning: A Workbook,”* Landau: Bildungstransfer, 2011.

[2] Y. Engeström, *“Learning by Expanding,”* Cambridge: Cambridge University Press, 2014.

[3] M. Weiser, *“The Computer for the Twenty-First Century,”* Sc. American, no. 9, pp. 94-104, 1991.

[4] M. McLuhan, *“Understanding Media: The Extensions of Man,”* New York: McGraw-Hill, 1964.

[5] K. Reich, K., “Interactive Constructivism in Education,” *Education and Culture,* vol. 23, no. 1, pp. 7-26, 2007.

[6] H. Maturana and F. Varela, *“The Tree of Knowledge. The Biological Roots of Human Understanding,”* Boston: Shambhala Publications, 1992.

[7] P. Bordieu, “*Language & Symbolic Power,”* Boston: Harvard University Press, 1991.

[8] J. Piaget, “The Role of Action in the Development of Thinking,” in *Knowledge and Development,* Springer, pp. 17-42, 1977.

[9] L.S. Vygotskij, *“Thought and Language,*” Cambridge: The MIT Press, 2012.

[10] A.N. Leont’ev, *“Activity, Consciousness, and Personality,”* Englewood Cliffs: Prentice Hall, 1978.

[11] T. Winkler, F. Scharf, C. Hahn, and M. Herczeg, "Ambient Learning Spaces," in *Méndez-Vilas, A. (Ed.) Education in a Technological World: Communicating Current and Emerging Research and Technological Efforts.* Badajoz, Spain: Formatex Research Center, pp. 56-67, 2011.

[12] B. Feldner, S. Günther, F. Schmitt, T. Winkler, M. Herczeg, “A Dolphin Is a Dolphin Is a Dolphin? Multimedia Enriched Learning Objects in NEMO,” in *9th Intl. Conference on Advanced Learning Technologies (ICALT 2009)*, Riga, Latvia, IEEE Comp. Society, pp. 29-31, 2009.

[13] S. Lob, J. Cassens, M. Herczeg, and J. Stoddart, "NEMO - The Network Environment for Multimedia Objects," in *Proceedings of the First International Conference on Intelligent Interactive Technologies and Multimedia*, Allahabad, India, ACM, pp. 245-249, 2010.

[14] T. Winkler, D. Bouck-Standen, M. Ide, A. Ohlei, and M. Herczeg, “InteractiveWall 3.1 - Formal and Non-Formal Learning at School with Web-3.0-based Technology in Front of Large Multi-touch Screens,” in *EdMedia 2017: World Conference on Educational Media and Technology*, Washington, DC: AACE, pp. 1317-1326, 2017.

[15] T. Winkler, S. Günther, and M. Herczeg, "Moles: Mobile Learning Exploration System," in *Proceedings of the Society for Information Technology & Teacher Education International Conference (SITE 2009)*, Charleston, SC: AACE, pp. 348-351, 2009.

[16] A. Ohlei, D. Bouck-Standen, T. Winkler, and M. Herczeg, “InfoGrid: Acceptance and Usability of Augmented Reality for Mobiles in Real Museum Context,” in *Mensch und Computer 2018 - Workshopband*, Berlin: De Gruyter, pp. 340-344, 2018.

[17] A. Ohlei, D. Bouck-Standen, T. Winkler, and M. Herczeg, “InfoGrid: An Approach for Curators to Digitally Enrich their Exhibitions,” in *Mensch und Computer 2018 - Workshopband*, Berlin: De Gruyter, pp. 345-352, 2018.

[18] D. Bouck-Standen, A. Ohlei, V. Daibert, T. Winkler, and M. Herczeg, “NEMO Converter 3D: Reconstruction of 3D Objects from Photo and Video Footage for Ambient Learning Spaces,” in *AMBIENT 2017 - The Seventh International Conference on Ambient Computing, Applications, Services and Technologies*, IARIA, pp. 6-12, 2017.

[19] D. Bouck-Standen, A. Ohlei, S. Höffler, V. Daibert, T. Winkler, and M. Herczeg, “Reconstruction and Web-based Editing of 3D Objects from Photo and Video Footage for Ambient Learning Spaces,” in *Intl. Journal on Advances in Intelligent Systems*, vol. 11, no. 1/2, pp. 94-108, 2018.