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Ambient Learning Spaces: Systemic Learning in  
Physical-Digital Interactive Spaces

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# Ambient Learning Spaces: Systemic Learning in Physical-Digital Interactive Spaces

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## 1 Introduction

We developed and discuss here a new system concept for digitally-enabled teaching and learning environments that include classical electronic media concepts and enables a pedagogy that is only possible through the ubiquitous dynamic new digital media. The basic concepts for our *Ambient Learning Spaces (ALS)* environment have been based on contemporary pedagogical theories, such as those described in *Assisted Learning* by Arnold (2011) or *Expansive Learning* by Engeström (2014) taking into account that learning processes are becoming 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 (1991), self-driven and creative learning supported by such a digitally enriched, ubiquitous learning environment has a high potential for future education. Technical, methodological, as well as 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 generally available ubiquitous digital extensions of ourselves in the sense of McLuhan's *Extensions of [Hu]Man* (1964). Learning has to be oriented towards a living learning process in which learners discover and construct new and different knowledge structures and content. Especially in highly digital and therefore increasingly virtual environments, joint learning and references to the real world seem to be important for grounding and progress. This implies the need for body- and space-related digital learning. As the human body and human perceptual abilities, as well as the sensomotorical skills

are the foundation for aesthetic processes, ALS is able to naturally serve as a platform to foster aesthetic and creative learning.

## 2 Methodology

The concept and implementation of *Ambient Learning Spaces* or short *ALS* is based on several methodological foundations. In this section, we will refer to some of the more important pedagogical theories as well as the resulting systemic model of ALS.

### 2.1 Pedagogical Foundations of Ambient Learning Spaces

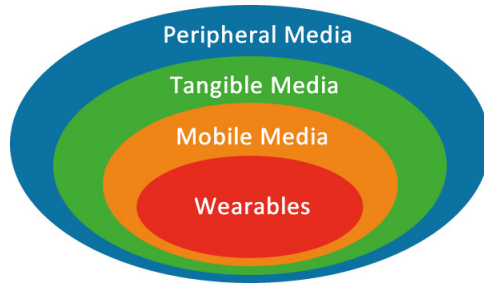
At the end of the 20th century and now in the 21st, pedagogy and didactics mostly follow interactionist-constructivist (e.g., Reich 2007) and systemic-constructivist approaches (e.g., Arnold 2011). Contemporary didactic approaches assume that learning is an active construction process, where a learner creates an individual aesthetic and algorithmic (functional) representation of the world. However, this process is not purely subjective, as early constructivists like Maturana and Varela (1992) hypothesized since each subject is in relationships with other subjects within different communication communities. Via communication systems, any statement about reality is subject to viability, because of changes in interests, power possibilities, as well as social, economic, cultural, symbolic capital formations in the sense of Bourdieu (1991). Learning thus depends strongly on individual prior knowledge and the social, natural and technical environment, in which learning takes place. Individual aesthetic expression and communication will drive creative co-construction processes.

Even when we have to question Piaget's rigid step-by-step development model (1977) because of the social, societal and cultural influences of learning, his 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 contextualized by challenges and learning contexts. As a result, learning is not passive storage, but active and creative construction of knowledge, which should be supported by learning environments. In contemporary constructivist models, the role

of a teacher is not to impart knowledge, but to support learners in their individual learning processes through a balanced measure of instruction. The learners shall independently deal with learning content, for example by content selection, discovery of relations, and algorithmic combination of 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 (2012) and Leont'ev (1978) and further differentiated in *Critical Psychology for Self-Determined Learning* by Holzkamp, as discussed by Engeström (2014). 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 references. Thus, Expansive Learning addresses individual or collective learning processes with the goal of extending action possibilities, competencies, and self-determination within processes of co-construction.

This means for 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 and supporting the individual construction of sustainable knowledge, i.e. knowledge that finds relevance of use in the reality of daily life. In this case, these systems support individual and also cooperative learning by establishing a strong relationship to the physical world connected to the human body as well as the social reality of the learners. In a 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 not only mentally, but even bodily. Learning software, which uses such capabilities of new interactive interfaces, has high potential to support creative learning processes and collaboration as expressions of aesthetic co-construction, and, above all, a relevant relationship to life physically and mentally.



*Figure 1.* Shell model of ubiquitous media used in ALS. (Own work)

## **2.2 Requirements for a Systemic Media Platform for Contemporary Pedagogy**

To support constructivist pedagogical concepts, including the world of current digital media, we need a systemic technological concept for a digital media platform that can be connected to real world contexts during teaching and learning. The platform has to serve as the technological substrate of digital aesthetics as well as algorithmic teaching and learning inside and outside the classroom.

Media created or provided need to be accessible by a variety of interactive frontend applications by the learners for stationary and mobile usage and have to be re-usable and re-combinable in different teaching and learning contexts. Access to the media is possible through user interfaces that permit different interaction forms, like image and video viewers, interactive form filling, algorithmic image and video graphs, as well as augmented and virtual realities or even wearables.

A technological multimedia platform for teaching and learning needs to support a wide variety of media types like text, sound, image, video and 3D objects. Media shall be constructible as a structured collection of basic media for different input and output devices. The platform needs to be able to dynamically generate device dependent variations of source media like images, videos or 3D objects with a specific format or resolution as needed. For example, mobile smartphones will be provided with lower resolution images than large public screens. The conversion of media shall be performed in automatic processes. The platform shall provide flexible per-

sonal, group and public ownerships for media objects or collections of them.

The media created need to be enriched by informal annotations referring to the application contexts. Additionally, they shall have relations to higher level concepts like taxonomies referencing to the global DBpedia or self-constructed taxonomies of knowledge. These formal relationships together with the informal tags will transform the media into *semantic media* related to real world and real usage. Tags usually stem from ad hoc references during social use. Certain tagging shall be done semi-automatically from the context of use itself, like the project ongoing or geographic and chronological references throughout the process of use.

The media need to be hosted and organized in a *cloud-based distributed media database* to be accessible anytime and anyplace for contextualized learning and teaching.

### 3 The ALS Architecture and Applications

In over 10 years of research we developed a system with capabilities described in the previous section. The system has been called *Ambient Learning Spaces (ALS)* (Winkler et al. 2011, Herczeg et al. 2019). The pedagogical requirements described in the previous section have been translated into a technical ALS system architecture (Herczeg et al. 2020a, b).

#### 3.1 The ALS Learning and Teaching Applications

The ALS environment provides an increasing number of different application modules (Fig. 2) used by learners and teachers to initiate and organize learning processes. These hardware and software modules can be used to construct and enrich specific learning contexts. All of these frontend modules use the same backend and middleware system called *The Network Environment for Multimedia Objects (NEMO)* (Feldner et al. 2009, Lob et al. 2010) with common backend features and a shared storage layer for all multimedia objects generated and used during the learning processes. In the following subsections, some of the most important and most advanced modules will be outlined and shown. New modules can be added dynamically to the flexible and open ALS platform.

Location-based Media Dialogical and Interactive Opposite		Location-independent Media Extended Self	
Peripheral Media	Tangible Media	Mobile Media	Wearables
Act <sup>o</sup> Motion	InteractiveWall MediaGallery Timeline SemCor Hypervid	MoLES InfoGrid	Smart Fashion

Figure 2. ALS teaching and learning applications. (Own work)

### Interactive Wall (IW)

As a central integrative element, built as a stationary frontend for classrooms or school foyers, we implemented a system called the *Interactive Wall (IW)*. The IW is a social entry and access point for teachers and learners and supports cooperative learning (Winkler et al. 2017). It consists of an arbitrary number of large interactive displays that can be installed in buildings and rooms (Fig. 3). The displays consist of multiple affordable TV screens which are equipped with touch-sensitive frames. The large displays are connected to a distributed array of client computers, which themselves are connected to NEMO. Most of the ALS learning applications can be accessed or controlled through an IW.



Figure 3. The Interactive Wall (IW) as a social access point to ALS. (Photo: own work)



## MediaGallery

The *MediaGallery* is an application running on the IW. As the IW is providing public interactive displays, the *MediaGallery* enables learners to *explore personal, group-based or public media collections* about their learning topics (Fig. 4). Each collection consists of a set of images, podcasts, videos, documents or 3D objects that are either manually combined or selected by semantical correlations and search. When multiple media galleries are available, the IW has an area to place randomly selected dynamic previews of public media collections on the IW. Media collections display, connect and separate content. They represent ownership and topical common ground.

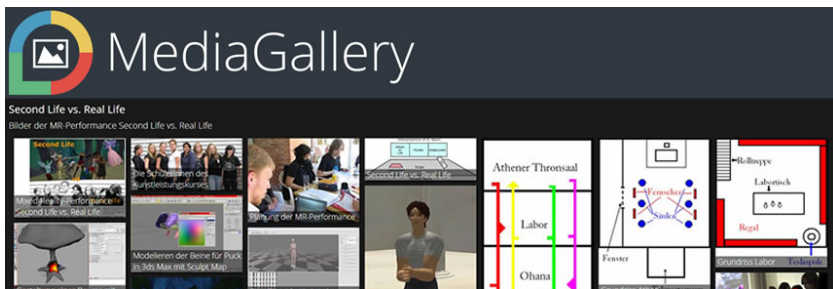


Figure 4. A sample media collection in the *MediaGallery*. (Screenshot: own work)

## TimeLine

*TimeLine* is a learning application running on an IW. It presents a multi-dimensional visual structure to do research on historical events showing chronological correlations between events of selected topics on several timelines (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 access to the most interesting content. Each entry on the *TimeLine* can contain media files such as text, photographs, or video clips. To analyze entries inside the *TimeLine* in detail, elements can be further explored in other modules like *SemCor* (see next section). From a pedagogical point of view, the *TimeLine* presents *chronological correlates in several parallel time threads* (Herczeg et al. 2020b).

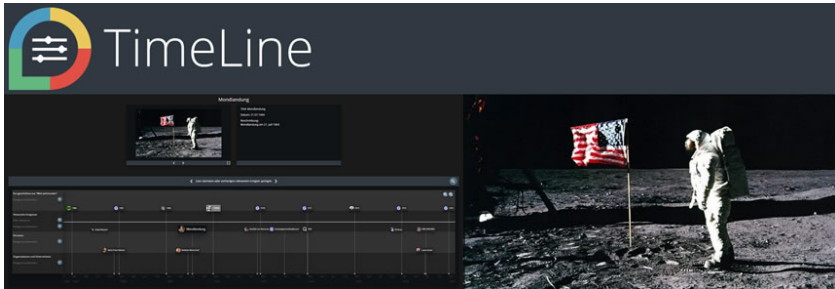


Figure 5. TimeLine to interact with chronological knowledge.  
(Screenshot: own work)

## SemCor

*SemCor (Semantic Correlation)* is another application available on the IW. Students explore information elements along with semantic relationships provided by the global DBpedia database. Ontologies are leading to knowledge chunks related to each other in a semantic mesh (Fig. 6). While being used, the system is constantly searching the World Wide Web for new entities related to the already displayed and selected ones. Different algorithms to calculate similarities and differences of such entities help to choose from a large number of candidates found to be displayed. *SemCor* gives *insights to very large information repositories and supports associative learning based on serendipity as well as student's own curiosity* (Herczeg et al. 2020b).



Figure 6. SemCor interacting with knowledge entities and relations  
(Screenshot: own work)

## MoLES

*MoLES* is a web application for smartphones and tablets to support *task-oriented teaching mainly outside school* for example in urban space, natural habitats or museums (Fig. 7). Teachers or more advanced students can define structured tasks to be solved within project-oriented teaching (Winkler et al. 2009). The students will work on tasks like challenges, which they have to solve mainly outside school. While completing the tasks they create and collect media entities captured with their mobiles. These media will automatically be uploaded into the NEMO system and become available for further use as a documentation of results in a project-centered media gallery (Herczeg et al. 2020a).

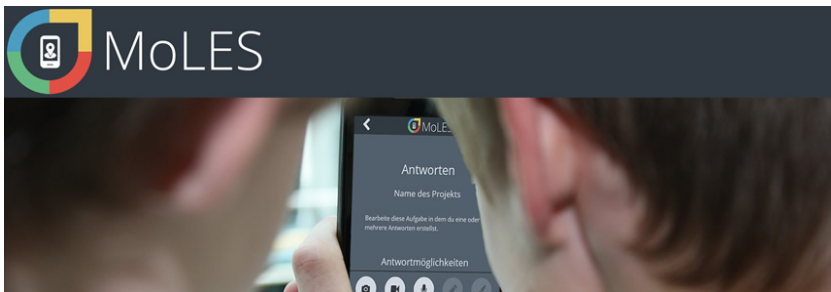


Figure 7. MoLES, a mobile task-oriented system. (Photo: own work)

## InfoGrid

*InfoGrid* is a mobile 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 (Ohlei et al. 2018a, b, Herczeg et al. 2020a). InfoGrid can be used in places where the image targets that trigger the augmentations are available. When the app is started, it shows the physical environment on the mobile screen along with overlaid virtual information (Fig. 8). Students can, for instance, use InfoGrid to create augmented posters for their projects, set up exhibitions of physical artifacts or create AR games inside or outside school.

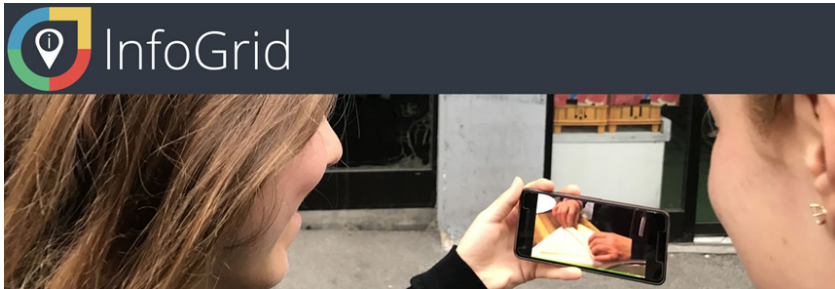


Figure 8. InfoGrid, a mobile AR system. (Photo: own work)

### 3.2 The ALS Portal and the ALS Authoring Systems

For a learner-centered self-driven learning process it is a basic requirement that students and teachers themselves are capable of creating and annotating media and their aesthetic expression as well as managing the platform by defining users or by activating or deactivating certain applications. Therefore, we developed a web-based management module called *ALS Portal*, which provides the above mentioned functionalities. To enable teachers and students to manage their created media we also developed several authoring tools to work with images, videos, and 3D objects. Furthermore, we created tools to support the placement of virtual objects in physical settings for AR applications.

#### 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 IW. After logging into the ALS Portal, a list of ALS applications will be presented, which are available for the current user (Fig. 9). The user can then create or edit information. All data entered through the ALS Portal will be stored inside the central NEMO backend.

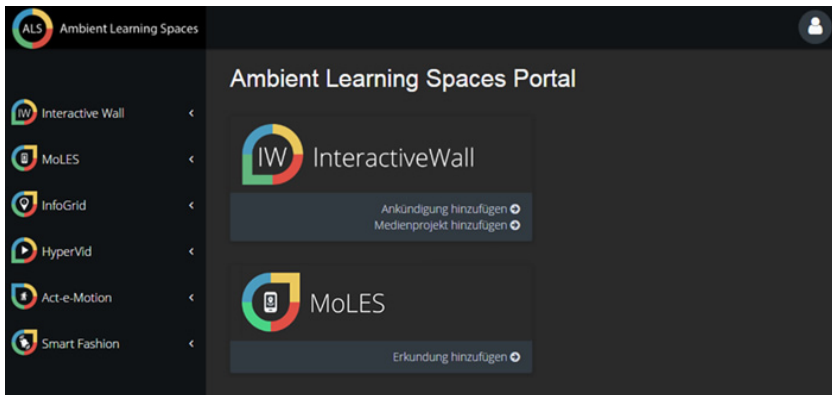


Figure 9. ALS Portal for management of ALS applications and content. (Screenshot: own work)

## VideoEdit

*VideoEdit* is an easy to use 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 PC. 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 additional functions such as increasing and decreasing the volume of the resulting video. After preparing a video, *NEMO* renders the video using the *FFMPEG* framework. The resulting MP4-file is automatically made available for ALS applications.

## 3D Converter and Editor

We implemented a special functionality called *NEMO Converter 3D (NOC3D)* for the automatic generation of 3D objects from 2D video and photographic footage (Bouck-Standen et al. 2017, 2018a). The user can upload videos or photos into *NOC3D*, which automatically processes these files using photometric methods. After completing the process, the object converter delivers a 3D model stored in *NEMO*. The resulting 3D models usually contain unwanted artifacts and are randomly placed in space. *3DEdit* can then be used within the web-based ALS Portal to remove

unwanted artifacts from the 3D-Object and to change position, scale and orientation of the 3D object in space. After finishing this process, these objects can be used in other ALS applications such as the MediaGallery or InfoGrid.

### Narrator

With the *Narrator Module* of NEMO 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 (Bouck-Standen et al. 2018b). To experience the storylines created, for example the InfoGrid AR application can be used. The Narrator will guide the user depending on their topics of interest or earlier visits along a path of activities. The dramaturgical algorithmic structure can be created based on some classical models of drama like such from Aristotle or more contemporary ones.

### 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 (Bouck-Standen et al. 2018c). ALS has been used in different ways for language teaching and learning. 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 NEMO Services

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

### User Authentication

The Administrator of the ALS Portal can setup institutions (e.g. schools) and assign teacher accounts to a specific institution. With their accounts the teachers themselves can then create and edit accounts for the students (Bouck-Standen et al. 2018c). The teachers can also define student work (project) groups. Depending on the ALS application used, the teacher has the role of a moderator with rights to publish and unpublish information for public display or group use.

### Tracking

The NEMO framework includes a *Tracking Module* to anonymously log and track user requests from all ALS applications. To inspect the tracking data the ALS Portal contains a map-based tracking visualization module. This supports insights on preferences and possible obstructions. It shows statistics of applications used or media queries indicating how often media files are requested. The tracking function will help to optimize didactic concepts.

### 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, Cognitive Services analyze the selected media and provide suggestions for the user. The user can accept or reject the suggestions for tagging. The Cognitive Services layer has used artificial-intelligence-based methods for classification.

## 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.

### Central Logic

The ALS Central Logic of NEMO contains mechanisms to store and retrieve media content depending on applications and frontend devices as

well as ownerships of media. It connects the NEMO Services with the database.

### Semantic Database

NEMO makes use of a semantic database to store information in an 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. Information will be valorized into knowledge-based structures referring to meaning in the real world.

### 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 seen as a distributed cloud-based storage system for semantic teaching and learning content to serve any frontend environment and define ownership, digital rights and security needs. It can be hosted on a school server to keep all data within the institution.

## 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, inside and outside school as well as in museums.

### 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 anonymously via NEMO providing detailed statistical data. Teachers and other authorized persons can check how often the applications are used inside the ALS Portal. Furthermore, the access of the media themselves and the media volumes created over time can be analyzed. This allows discussing the practical values of the applications with respect to their pedagogical relevance and effort by the teachers themselves.



ALS applications have been used so far by several hundred teachers in more than 20 different schools on all class levels to construct their own understanding of the digital transformation in school. Every teacher has personal didactic methods and pedagogical values. It would be of no use to evaluate the ALS environment pedagogically as a fixed solution independent of the special needs, constructs and contexts of usage. However, the modules have proven to be helpful in a variety of teaching contexts over school terms. In many cases these contexts have been characterized by aesthetic-creative processes based on information modeling with aesthetic digital media and their appreciation.

We have been providing seminars for teachers to train the use of different applications technically as well as didactically through the German Institute for Quality Development at Schools Schleswig-Holstein (IQSH).

### Usability and User Experience

The frontend applications have been developed in user-centered development processes under participation of many 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 aesthetic design quality besides the usability and user experience of the functionality through many development cycles. Most of the applications show a high level of usability. However, being a living platform there are always new applications, which are still in an early stage of development and evaluation.

### 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#. Besides SQL modules, the database layer has been built with the BrightstarDB framework. Frontends have been implemented mostly for web browsers in HTML5 and CSS3 or as native apps for iOS and Android for mobiles.

The ALS system is a large hardware and software system that has been tested in many ways to deliver the performance that is needed inside and outside school. The current system is able to host 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 running environment that is currently used on a daily basis by several schools and museums. However, being still a prototypical research environment with a limited operational dimension, ALS can at least serve as a blueprint for future digital platforms for educational use in general.

## 5 Conclusions

Ambient Learning Spaces (ALS) is a large prototypical teaching and learning environment for a wide variety of learning contexts with aesthetic and creative learning processes at school. ALS has been based on contemporary learning theories like Assisted or Expansive Learning bringing the learners into an active constructive role.

A semantic media repository allows the use and reuse of media in different contexts and for different interaction devices. A suite of modular learning applications for stationary and mobile learning has been built, applied and evaluated in real teaching contexts. The usability tests and pedagogical case studies show that 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. It addresses directly aesthetic processes in perception and action. The applications are modular and the media reusable to enable the teachers to adapt and reuse the ALS system and their media content according to teaching needs and allow creative iterations within and across groups of learners. ALS are ubiquitous and pervasive and do not imply or force didactical methods. It has been made available to a large number of schools and museums over several years.

ALS show the transition from computers used as digital media to a digital knowledge platform for constructive teaching and self-directed aesthetic and algorithmic learning.

## 6 Acknowledgements

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