AMBIENT LEARNING SPACES: BYOD, EXPLORE AND SOLVE IN PHYSICAL CONTEXTS

M. Herczeg, A. Ohlei, T. Schumacher

University of Lübeck (GERMANY)

Abstract

There is a worldwide discussion about digitization in school education. This discussion is mostly technology-centered, leaving a lack of solutions for daily schooling or focuses on isolated educational applications. With the Ambient Learning Spaces (ALS) platform, we developed a didactic infrastructure as an integrated environment that supports self-directed learning inside and outside school. The platform interlinks mobile and stationary learning applications. The artificial division between the classroom and the world outside vanishes through the pervasive cloud-based backend system NEMO (Network Environment for Multimedia Objects) connecting students' mobile applications with central semantic media storage. This paper emphasizes on the two mobile applications for task-oriented (MoLES) and discovery-oriented learning (InfoGrid). The InfoGrid System is a mobile application that supports the creation of augmented reality tours enabling the learners to study and discover physical places like urban spaces, architecture, museums, industrial settings, or natural habitats. Physical objects will be overlaid by media like text, images, audio, video, or 3D objects augmenting the physical/natural world with a digital informational layer by discovering and selecting visual (photographic) targets. Teachers or students can create content and tours by themselves through a modeling and editing application. The mobile application Mobile Learning Exploration System (MoLES) allows setting up tasks (challenges) to be solved by students inside and preferably outside school. Tasks can be created by teachers or students themselves depending on the pedagogical goals. The students use their own smartphones or tablets to solve these tasks by collecting information in form of different media like texts, photos, audio recordings or videos. This information will then be tagged and transmitted to NEMO. When the tasks have been solved, the students return to school and use the information collected for presentations in the classrooms or the school foyer. Both mobile applications make use of large multi-touch screens (InteractiveWall) or multi-touch tables (InteractiveTable) located in their school to discuss, sort and structure the media into media collections by a tool called MediaGallery for further use. Using their own digital devices in the sense of "Bring your own Device" (BYOD) in a physical environment keeps the students connected to their physical (real) world. They will solve tasks, discover interactive content in a project- and topic-oriented manner outside school and bring the results back to the classroom to be discussed in a structured way.

Keywords: Ambient Learning Spaces, Mobile Learning, Augmented Reality, Semantic Modeling, Multimedia Learning.

1 INTRODUCTION

The worldwide ongoing discourse about digitization in school education is often highly technology-centered, leaving a lack of solutions for daily schooling or focuses on isolated educational applications. Neither Wi-Fi at school nor electronic whiteboards, desktop-PCs, tablets, or smartphones will be the answer. However, they can be a key for a solution, if there is a didactic infrastructure that connects and integrates these devices, often owned by the learners themselves in the sense of *"Bring your own Device (BYOD)"* into methods of self-directed learning. This idea follows, among others, the conceptualizations of Weiser [1], where there will be a range of different sizes and form-factors to enable people accessing personalized knowledge sources any place at any time.

With the *Ambient Learning Spaces (ALS)* platform ([2], [3]) we developed a didactic infrastructure as an integrated and pervasive environment that supports self-directed learning inside and outside school. The platform connects mobile and stationary learning applications. The artificial division between the classroom and the world outside vanishes through a pervasive cloud-based backend system called *NEMO (Network Environment for Multimedia Objects)* connecting students' mobile applications with a central semantically tagged and structured media storage. This paper emphasizes on two mobile applications for *task-oriented learning (MoLES)* and *discovery-oriented learning (InfoGrid),* both being part of this integrated infrastructure.

ISBN: 978-84-09-24232-0

The *InfoGrid System* is a mobile application that supports the creation of augmented reality tours enabling learners to study and discover physical places like urban spaces, architecture, museum exhibits and archives, industrial settings, and even natural habitats. Physical objects will be overlaid by media like text, image, audio, video, or 3D objects augmenting the physical world by a digital information layer through discovering and selecting visual (photographic) targets in the scenes. Teachers or students can create content and tours by themselves with the help of modeling and editing applications. Users of InfoGrid can download the app and use it on their own mobile devices.

The mobile application *Mobile Learning Exploration System (MoLES)* allows creating tasks (challenges) to be solved by students inside and preferably outside school. These tasks can be created by teachers or students themselves. The students may use their own smartphones or tablets to solve these tasks by collecting information in form of different media like text, photo, audio, or video. This information will be tagged and transmitted to NEMO. When the tasks have been solved, the students return to school and use the information collected for presentations in classrooms, the school foyer or other places.

Both mobile applications make use of large multi-touch screens *(InteractiveWall)* or multi-touch tables *(InteractiveTable)* located in the school to discuss, sort and structure the media into media collections by a module called *MediaGallery* for further use. Using their own digital devices in a physical environment keeps the students connected to their physical (real) world. They will solve tasks, discover interactive content in a project- and topic-oriented manner outside school and bring back the results to the classroom to be discussed and worked out in a structured way under teachers' guidance.

Teachers and learners are enabled to use the different modular teaching applications of the ALS system as a modeling environment as well as learning applications. An overview of the whole system can be found in [3]. ALS installations are currently in daily use in several schools and museums.

2 METHODOLOGY

Ambient Learning Spaces (ALS) learning applications are based on several methodological foundations. In this section, we will discuss some pedagogical theories, especially about learning in context, and outline the resulting systemic model of ALS.

2.1 Pedagogical Foundations

In our digital age, there are endless discussions about the usage of computers, networks and computer applications in the classroom. Most of the applications are dealing with generic skills like writing, math or with abstractions of the world like geography, politics or economy. However, only a few computer-supported pedagogical knowledge discourses can be seen incorporating the role of the human body and senses and about being situated in the physical context during the learning process. As computers have been developed into many different form factors, sizes and user interfaces we now can return to more natural learning settings outside school taking the digital tools with them. Mobile computers combined with cloud-based computing are not only capable to deliver their services anytime at anyplace; they can also connect the learner to the real problem domains by *being in context* during the learning process.

Montessori's pedagogy, developed already in the beginning of the last century, identified didactic foundations for learning relating and connecting the learners with all their senses and motor skills to the surrounding physical world*: "... the tiny child's absorbent mind finds all its nutriment in its surroundings. Here it has to locate itself, and build itself up from what it takes in ..."* [4]. Later, following the culture-based theory of Vygotskij [5] combined with the activity-based theory of Leont'ev [6], Cole and Engeström define a system of mediating artifacts relating the subject with the objects of the world surrounding them (Fig. 1): *"Cultural artifacts are both material and symbolic; they regulate interaction with one's environment and oneself. In this respect, they are 'tools' broadly conceived …"* [7].

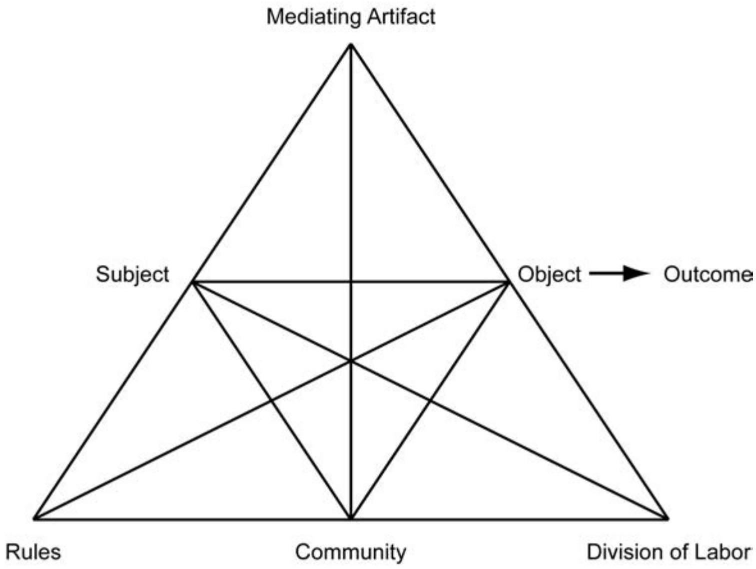

Figure 1. Activity Analysis (cf. [7]).

Cultural artifacts or tools, like the computer, foster self-determination by building up personal knowledge in social relationships within the cultural context. The key issue, in the end, seems to be self-directed and activity-based learning in complex real-world contexts incorporating the physical world, the social structures and rules, as well as the cultural settings together with digital representations of the "world knowledge". Learning then takes place as situated action, where tools (computers) play the role of mediators to the surrounding world*: "Child's thought processes are inextricably tied to the structure of the external activity that initiated this learning."* [8] Learning environments therefore shall be designed for:

- *Authentic Activities* using age-appropriate tools in similar activities to those of adults,
- *Construction of Artifacts* and sharing them with their community, and
- *Collaboration* between experts and students, individual learners and fellow learners.

As a result, following the pedagogical foundations of body- and space-related learning in a social and cultural context connected to the world seems to be a promising way to support self-directed, meaningful and experience-based learning addressing the full complexity of the real world [9]. While the earlier years of computing in school were characterized by PC rooms, later concepts thought of more flexible computer systems like laptops. Today more and more students bring their own computing devices (BYOD) like tablets and smartphones connected to a high bandwidth network. Out of school teaching is therefore not only feasible, but also a chance to naturally return to human learning in its best way in the context of real world settings like the urban spaces, biotopes, or industrial areas. Incorporating artificial learning spaces like museums and archives outside school will enhance this "out of school"-teaching even more. However, it is not only the technology, like the gadgets or the networks, which is sufficient to let contextualized out of school learning take place. What we need are didactic instruments, kind of Vygotskij's *"cultural tools"* to support curiosity-driven learning activities in context by giving structure. They will be used to build up personal and social learning content connected to large knowledge environments of the world, like the World Wide Web and highly structured content like DBpedia, Wikipedia or dedicated digital archives.

In the following sections we will describe a backend platform with mobile applications that allows basically two ways of mobile learning:

1 *Task-based Learning* that issues challenges to the students to collect data (media) in certain contexts outside school, like urban contexts, museums, buildings or biotopes. Students have to solve the tasks and bring back data and media gathered to set up an information model about their topics when they come back to their school and classroom. The system we built for this purpose is *MoLES (Mobile Learning Exploration System)*.

2 *Discovery-based Learning* in a physical environment like urban spaces or museums, where physical artifacts will be enriched by digital information like text, images, audio files, videos or

static or animated 3D objects. The system we developed for this purpose is *InfoGrid*, an augmented reality app with dynamic loading of media and logic.

2.2 Ambient Learning Spaces

The two mobile applications *MoLES* and *InfoGrid* are modules of a larger integrating and embedding system called *Ambient Learning Spaces (ALS)* ([2], [3], [10]). ALS connects these mobile learning applications with a semantic repository as a *backend* system storing and semantically modeling and annotating the media for the frontend applications. Besides the mobile applications, there is a system of stationary large screen systems like the *InteractiveWall (IW),* often placed in school foyers and other public school spaces or in the classroom. The IW is a multi-touch interactive screen with a capability of up to 50 simultaneous touch events like when several students are interacting with the content. The IW comes in a variation as an *InteractiveTable* with the additional capability of recognizing not only touch events but tangible objects (fiducials) placed on the surface.

ALS is a didactic infrastructure providing modularized frontend applications on mobile and stationary interactive computer systems connected to a semantically modeled multimedia backend store called *Network Environment for Multimedia Objects (NEMO)*. As an open system, ALS can be extended by new media applications on any computer system. Currently, we are developing a 360º interactive VR application to drive large digital dome presentation systems. Ambient Learning Spaces are digital teaching and learning environments that can be used to implement the above mentioned forms of contextualized learning connecting in and out of school activities through one common storage system NEMO.

2.3 The Integrated ALS Backend Platform NEMO

The Network Environment for Multimedia Objects (NEMO) ([3], [11], [12]) is a service-based architecture (cf. Fig. 2) that provides:

- User Authentication (accounts and profiles for users and groups)
- Usage Tracking (anonymous tracking for user research)
- Media Conversion (automatic data conversion for 2D, 3D, and video footage)
- Cognitive Services (automatic tagging and classification)
- Central Logic (store and retrieve media content considering ownership and context)
- Semantic Database (tagged object- and RDF-based storage)

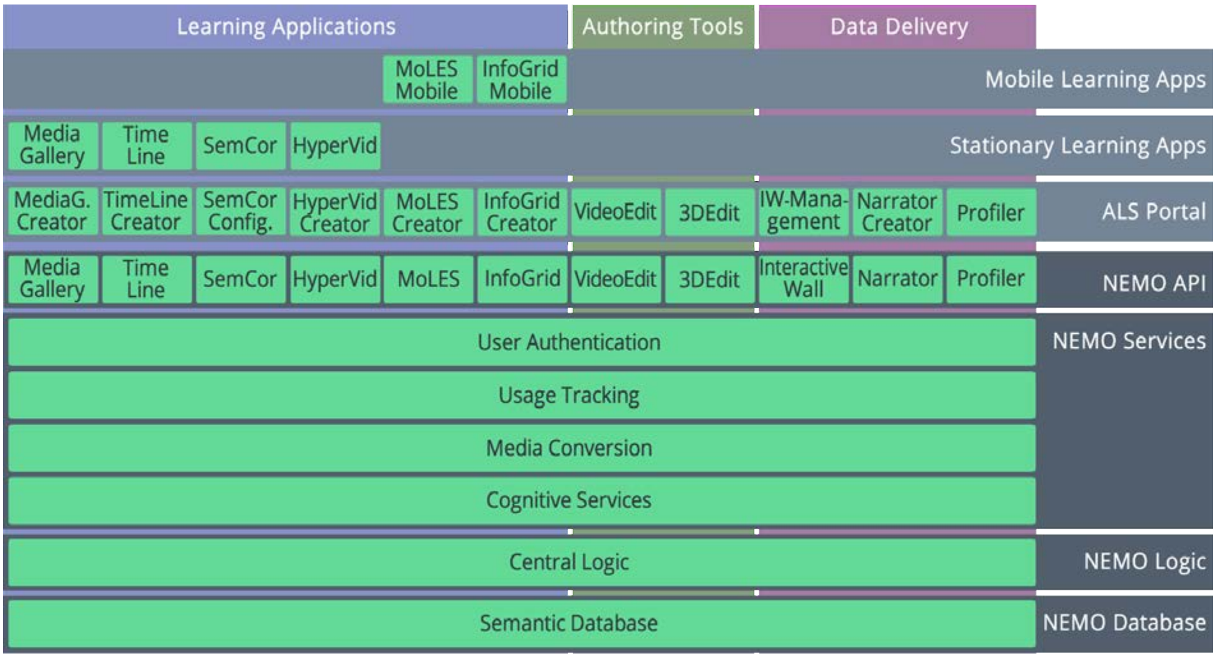

Figure 2. ALS System Architecture [3].

Media created and bound to objects representing the world are defining a semantic web. Several media in different formats for different devices can represent an object of the world. NEMO enables the learners to reuse media created or collected through one frontend application in other frontend applications for related but different learning contexts. This is important to create a growing repository of media that can be abstracted and enriched to symbols through annotations and classifications.

2.4 The Mobiles of ALS

Authentic education through social activities in context is a constructivistic approach to build individual knowledge within a cultural setting. Learners leave school and enter cultural contexts like urban space, biotopes, industrial environments or cultural collections and archives like museums or libraries. With networked mobile applications on smartphones, tablets or wearables, the computing devices (knowledge tools) can be taken with the learners (BYOD) to keep the scaffold of teaching with them and enable them to study in context and collect data and media to be brought back to school.

The *MoLES (Mobile Learning Exploration System)* app will set up a task-based scaffolding framework to guide the learners through tasks and challenges along a path of learning in context. The system has been conceptualized, implemented and evaluated over years in several technological versions ([13], [14], [15], [16], [17], [18]). A task may be to collect photographs of plants or videos of urban settings, research and store certain data about the objects and contexts and follow the next task until the whole tour has been finished. Typically, the students will go out in groups with fewer devices than group members to be forced to discuss and decide together what shall be collected and stored ([15], [16]). The MoLES system will store or directly transmit the data to the NEMO backend system for later use.

Very differently, *InfoGrid* is an *augmented reality app* that allows studying a certain environment by looking for certain "active objects" by activating digital visual or auditory overlays in the form of images, audio or video clips, static or animated 3D models. The students, for example, browse a paleontological museum to enrich the collections of fossils by videos of the excavation sites or overlaying skeletons with animated 3D animal reconstructions. The system will display a region or floor plan to guide the students through the environment. They can take snapshots of the objects found and will be guided through the environment by printed signs or digital floor plans.

The content of MoLES (tasks) or InfoGrid (augmentations) can be created by easy to use authoring tools that can be used by teachers and students. So, for example, older students can design learning context for younger ones as their own reflections on knowledge they have been building up.

MoLES and InfoGrid are learning instruments or mediating artifacts in the sense of activity theory, to act in an authentic environment, discuss with experts and learn by discovery. They are examples of experience design within cultural learning environments [9].

2.5 The Stationeries of ALS

After searching, discussing and collecting in the real context, the students need to select and order their findings to answer questions or create abstractions of what they found. This again shall be a social process that will typically happen in school with larger devices in a larger group or class context. To visualize the findings they can make use of large screens on the wall called the *InteractiveWall (IW)* (Fig. 3) ([19], [20], [21]). The IW will provide so-called *MediaGalleries* that show collections of raw findings (media collections from the field) or collections of selected, grouped, tagged and classified media bound to objects of the learning domain. From these, the students can create presentations or documents under supervision and guidance of their teachers or parents at home.

Figure 3. Several InteractiveWalls in a school foyer [20].

Besides the InteractiveWall there is an *InteractiveTable (IT)* that supports certain spatial working setups in school. Other than the IW, the IT will allow the use of tangibles, i.e. objects that can be placed on the IT and interact with the collections for example as tools for tagging or filtering.

Learning applications supporting semantic modeling about knowledge entities *(SemCor)* and chronological structures *(TimeLine)* connected to media objects can be used on the IW or IT as well (see in same proceedings [22]).

IWs and ITs have been placed in social areas within school buildings like the school foyer that will allow social interaction with media collections or presentations of contextualized projects as described above. Additionally, IWs can be used as general information terminals for any purpose.

3 THE MOBILE APPLICATIONS MOLES AND INFOGRID OF ALS

Students can use InfoGrid and MoLES on their mobiles inside and outside the school buildings. To setup projects for MoLES and InfoGrid, teachers and students can use the web-based ALS-Portal from any place through the Internet. All project- and task-related information entered into the ALS-Portal are saved in the NEMO backend system. The MoLES and InfoGrid frontend applications are also connected to NEMO and can provide access the saved projects. In the following two sections, MoLES and InfoGrid will be presented in more detail.

3.1 MoLES - The Mobile Learning Exploration System

Teachers can create new MoLES projects for the students using the ALS-Portal. When setting up a project, the teacher has to define a *title*, a *description* and an *image* for the project. Then multiple physical locations can be added, where students have to solve the tasks. After the definition of the locations, the teacher can set up one or multiple tasks for each created location (Fig. 4). Each task can contain a title, a description and media files. Furthermore, a task can be assigned to a group of students, who are supposed to complete it. All data entered into the ALS-Portal is saved in the NEMO backend system.

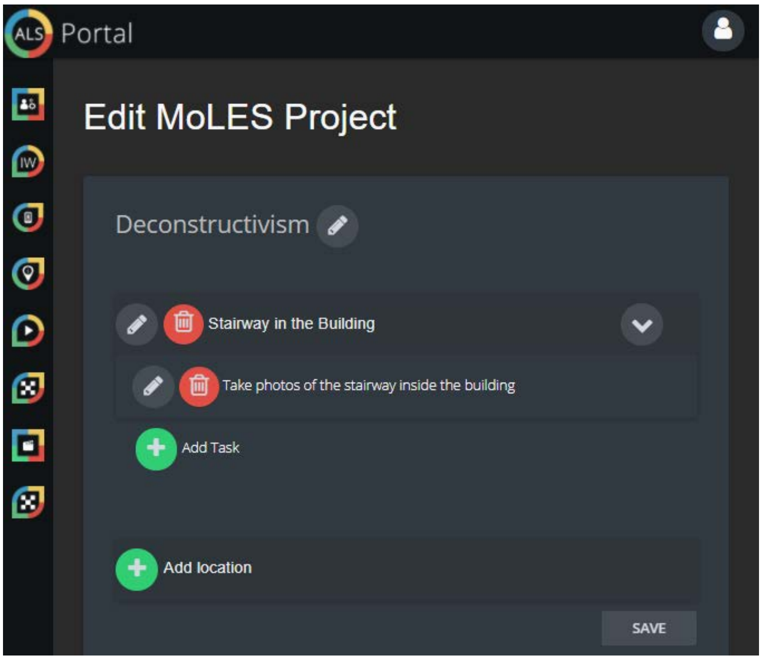

Figure 4. ALS-Portal view which shows the dialog for the editing of MoLES projects. The displayed project contains one location with one assigned task.

The MoLES frontend application is a web-based app running in any mobile browser. Students can access the MoLES webpage and log in using their mobile phones. Afterwards, a list of all available projects is presented to them. After making a selection, all locations available for the project are listed and they can choose the starting point. Arriving at the physical location students can solve the tasks taking photos or creating media files such as audio and video recordings (Fig. 5). All media files will be uploaded into the NEMO repository and will therefore be available for presentations or other purposes in class or the school foyer. More details and projects about MoLES, its conceptualization, and school projects with their evaluations and results can be found in ([13], [14], [15], [16], [17], [18]).

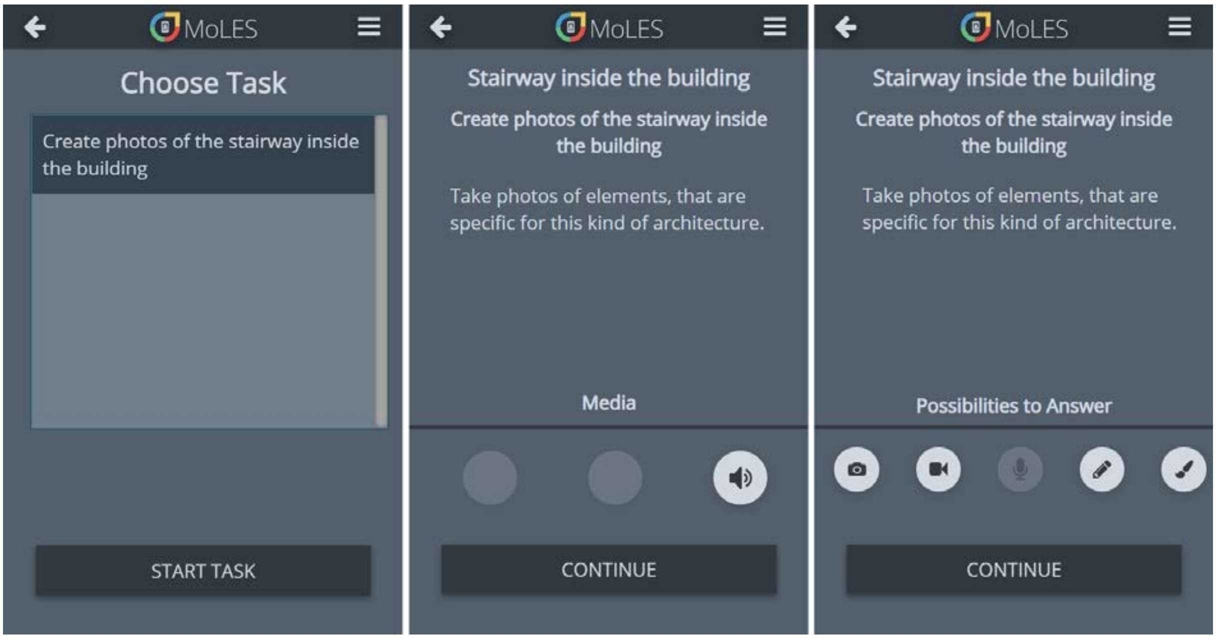

Figure 5. The MoLES mobile app. Left: After selecting a project and going to a defined location the MoLES app shows a list of open tasks for that location. Middle: The task details are shown and media files explaining the task are provided. Right: Each task can have different possibilities to be answered. It is possible to take pictures, record video or audio files, make notes, or make sketches.

3.2 InfoGrid - The Augmented Reality Experience

InfoGrid is an augmented reality app for educational purposes ([23], [24]). Teachers or students can create new *InfoGrid* projects using the ALS-Portal through a web-browser at school or home. When setting up a project, it is mandatory to define a *title*, a *description* for the project, and upload a *target database* (Fig. 6). We also implemented an option to add tour-related information as start options that will be displayed when starting the project on the mobile. They can contain a textual description, a thumbnail, or a video file. They are used to welcome the user, introduce the project and show where and how to find the targets in physical space. After saving the new project, the ALS-Portal redirects the user to the tour elements definition page. For any defined target in the scene, an AR overlay function such as an image, video or 3D overlay can be assigned.

For the production of 3D objects from image and video footage, a special converter has been developed that can be used by teachers or students themselves. For this purpose photos or videos of physical 3D objects will be taken. A special module of the NEMO media conversion layer, as well as the 3DEdit authoring system, will be used to create these objects (cf. Fig. 2). Details about these 3D modules and results about their usage can be found in ([25], [26], [27]).

Upon start, the InfoGrid mobile app connects to the NEMO backend and downloads a list of available tours. Once the user selects a project, the app downloads the necessary information to the mobile device. As soon as the download is complete, the user can see an optional intro regarding the selected project. When the mobile device is facing one of the prepared targets in the physical space, the app displays the augmentation through the display of the mobile device (Fig. 7). In case of audio and video augmentations, the app streams the audio and video data from the connected NEMO repository.

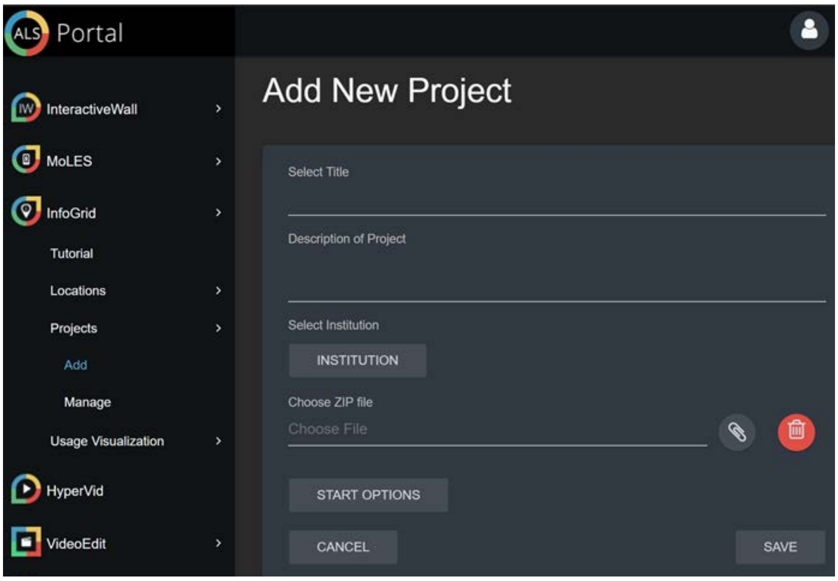

Figure 6. Screenshot of the ALS-Portal page for adding new InfoGrid projects.

Figure 7. The InfoGrid app displays a 3D whale skeleton augmented over corresponding physically exhibited bones inside the Museum for Nature and Environment in Lübeck, Germany.

3.3 Evaluations of the Mobile Applications

MoLES and InfoGrid were developed in user-centered development processes. Multiple formative evaluations with teachers and students have been done, improving the systems over the years. We also used the feedback we collected during workshops to improve the functionality of the system.

We monitored the system load for performance bottlenecks during usage. The results indicated that that the server performance shows no significant load even with larger groups of students using the system. Having the students run the apps on their mobiles, it will consume from their mobile data, if they are not in a free WiFi area. Some students might already have used up their available amount of mobile data. Therefore we concluded that it might be useful to provide a mobile WiFi hotspot, eventually in one of the smartphones carried, which the students can use as a group. We also noticed that the amount of available mobile data that the students have available is growing fast, so the topic is becoming less important in the near future.

Besides our teaching projects in schools, InfoGrid has been used by several museums for children and adults to provide AR experiences. In museum environments, we have evaluated the usability of the InfoGrid app with museum visitors using the short, but in real field environments very practical SUS Questionnaire [28]. The resulting usability score of the SUS test was 86.04 (SD=9.39; N=31; max. SUS-Score: 100), which is interpreted as excellent usability. We also assessed the usability of the 3D object placement feature within InfoGrid to set up AR tours, with a mean SUS score of 80.79 (SD=13.95; N=20), which is interpreted as a good usability. Participants mentioned that the interface is clear and easy to use. Students were able to set up AR tours without help of their teachers.

4 CONCLUSIONS

Ambient Learning Spaces (ALS) is a prototypical teaching and learning environment for a wide variety of learning contexts inside and outside of school. The learning applications are cultural tools in the sense of activity theory keeping the learners in an active role. A semantic media repository allows the reuse of media in different contexts and for different interaction devices. A large spectrum of modular learning applications for mobile as well as stationary learning has been built, applied and evaluated in real teaching and learning contexts.

In this paper, we emphasized the role of mobiles. Students may use *MoLES* to follow tasks and challenges and collect data and media. With *InfoGrid* they can try a more adventurous mode of discovery through augmented reality (AR). Both applications may be prepared by teachers for different topics and applications. We found that it was especially challenging and motivating for older students being the authors of tasks and AR tours for younger students.

Usability and pedagogical 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. The applications are modular and the media are reusable to enable the teachers to use and reuse the ALS system and their content according to their teaching requirements. ALS modules are ubiquitous and pervasive and do not imply or force any didactical method. ALS is currently piloted for three schools and three museums but has been made available to a larger number of institutions, who tried out the application and authoring modules over several years. Improvements and extensions are ongoing.

ACKNOWLEDGEMENTS

We developed and evaluated the ALS system described in the ongoing research project “Ambient Learning Spaces” supported from 2009–2021 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 in their institutions.

REFERENCES

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

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

[3] M. Herczeg, T. Winkler, and A. Ohlei, "Ambient Learning Spaces for School Education," in *Proceedings of iCERi 2019*, Seville, Spain, pp. 5116–5125, IATED, 2019.

[4] M. Montessori, "*The Absorbent Mind*," New York: Delta, 1967.

[5] L.S. Vygotskij, *"Thought and Language,"* MIT Press, 2012.

[6] A.N. Leont'ev, *"Activity, Consciousness, and Personality,"* Prentice Hall, 1978.

[7] M. Cole and Y. Engeström, "A Cultural-historical Approach to Distributed Cognition," in *Distributed Cognitions: Psychological and educational considerations* (G. Salomon, ed.), Cambridge University Press, pp. 1–45, 1993.

[8] R.K.E. Bellamy, "Designing Educational Technology: Computer Mediated Change," in *Context and Consciousness* (B.A. Nardi, ed.), pp. 123–146, MIT Press, 1996.

[9] M. Herczeg, "Experience Design for Computer-Based Learning Systems: Learning with Engagement and Emotions," in *Proceedings of ED-MEDIA 2004,* pp. 275–280, AACE, 2004.

[10] T. Winkler and M. Herczeg, "Pervasive Computing in Schools - Embedding Information Technology into the Ambient Complexities of Physical Group-Learning Environments," in *Proceedings of SITE 2005,* pp. 2889–2894, AACE, 2005.

[11] B. Feldner, S. Günther, F. Schmitt, T. Winkler, and M. Herczeg, "A Dolphin is a Dolphin is a Dolphin? Multimedia Enriched Learning Objects in NEMO," in *Proceedings of the 9th International Conference on Advanced Learning Technologies (ICALT 2009)*, Riga, Latvia, pp. 29–31, IEEE Computer Society, 2009.

[12] 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, pp. 245–249, ACM, 2010.

[13] A. Melzer, L. Hadley, M. Glasemann, and M. Herczeg, "Using the Moles and Mini Moles Software System to Bridge the GAP between Indoor and Outdoor Learning," in *International Journal on WWW/Internet,* vol. 4, no. 2, pp. 46–58, IADIS, 2006.

[14] A. Melzer, L. Hadley, M. Glasemann, S. Werner, T. Winkler, and M. Herczeg, "Using Iterative Design and Development for Mobile Learning Systems in School Projects," in *Proceedings of ICEC CELDA 2007,* Porto, Portugal, pp. 65–72, IADIS, 2007.

[15] S. Günther, T. Winkler, and M. Herczeg, "Mobile Learning with Moles: A Case Study for Enriching Cognitive Learning by Collaborative Learning in Real World Contexts," in *Proceedings of ED-MEDIA 2008*, pp. 374–380, AACE, 2008.

[16] T. Winkler, T., M. Ide-Schöning, and M. Herczeg, "Mobile Co-operative Game-based Learning with Moles: Time Travelers in Medieval," in *Proceedings of SITE 2008*, pp. 3441–3449, AACE, 2008.

[17] T. Winkler, S. Günther, and M. Herczeg, "Moles: Mobile Learning Exploration System," in *Proceedings of SITE 2009*, pp. 348–351, AACE, 2009.

[18] T. Winkler T. and M. Herczeg, "The Mobile Learning Exploration System (MoLES) in Semantically Modeled Ambient Learning Spaces," in *IDC '13 Proceedings of the 12th International Conference on Interaction Design and Children,* New York: pp. 348–351, ACM, 2013.

[19] T. Winkler T., M. Ide, and M. Herczeg, "InteractiveSchoolWall: A Digital Enriched Learning Environment for Systemic-Constructive Informal Learning Processes," in *Research Highlights in Technology and Teacher Education* (C.D. Maddux and D. Gibson, eds.), pp. 117–126, AACE, 2012.

[20] T. Winkler T., M. Ide, C. Hahn, and M. Herczeg, "InteractiveSchoolWall: A Digitally Enriched Learning Environment for Systemic-Constructive Informal Learning Processes at School," in *Proceedings of ED-MEDIA 2014*, pp. 2527–2537, AACE, 2014.

[21] 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 *Proceedings of ED-MEDIA 2017*, pp. 1317–1326, AACE, 2017.

[22] M. Herczeg, T. Schumacher, and A. Ohlei, “Ambient Learning Spaces: Discover, Explore and Understand Semantic Correlations,” in *Proceedings of iCERi 2020*, same issue, IATED, 2020.

[23] 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*, pp. 340–344, de Gruyter, 2018.

[24] 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*, pp. 345–352, de Gruyter, 2018.

[25] 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*, pp. 6–12, IARIA, 2017.

[26] 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.

[27] Ohlei, A., Bundt, L., Bouck-Standen, D., and M. Herczeg, "Optimization of 3D Object Placement in Augmented Reality Settings in Museum Contexts. Augmented Reality, Virtual Reality, and Computer Graphics," in *6th International Conference, AVR 2019,* Santa Maria al Bagno, Italy, Proceedings, Part II, 208–220, Springer, 2019.

[28] J. Brooke, "SUS: a 'quick and dirty' usability scale," in: *Usability Evaluation in Industry,* pp. 189–194, Taylor & Francis, 1996.