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Ambient Learning Spaces

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This chapter addresses body- and space-related learning of children and adolescents, supported by a wide range of media platforms. These media constitute ambient learning spaces, in which learners use a variety of annotatable multimedia objects (e.g. image, video, sound, 3D models). These multimedia objects can be used for e.g. mobile learning and for learning with tangible interfaces in different environments. Our research started more than a decade ago and relies on a pedagogical background known as critical constructivism. The development of our body- and space-related media is based on innovative scenarios and was done within a participative design process with future users. This media can be assigned to different layers of our *Model of Media Layers*. Technically, this is made possible by the *Network Environment for Multimedia Objects (NEMO), which is* currently under development. It offers contextualized, personalized, semantically rich, device-specific access to multimedia objects. The research on the innovative learning environments is founded on Design-Based Research. According to this approach theory and real-world usage are conjoined and of equal importance. Thus theory and applications evolve simultaneously during the design process.

Keywords: ambient learning spaces; learning environment; mixed reality; media layers; ambient media; tangible media; mobile media; wearable media; multimedia objects; design-based research; participatory design; critical constructivism; co-constructive learning

1. Introduction

The world of the 21st Century in which our children grow up will be permeated with digital enriched physical objects. Smaller and smaller computer systems will be part of a global network within the physical world [1, 2, 3]. For a decade, we have combined virtual and physical learning environments to so-called *Mixed Reality Learning Environments* [4, 5]. Mixed Realities foster pleasant learning processes and can be described as a result of experience design. The enrichment of the physical environment allows enactive learning which is supposed to be sustainable. At the same time, co-constructive learning processes are encouraged taking cultural and social space in learning environments into consideration. Further issues are the acquisition of transferable knowledge and the enhancement of the learners' competences.

In the following chapter we will introduce our concept of ambient learning spaces in the current scientific discussion. We will then present our latest research on prototypical interactive systems, their development, use and evaluation. Finally, we present the *Network Environment for Multimedia Objects (NEMO)*, which is currently being developed. NEMO offers access to multimedia objects through a cloud-based repository and enables their use on different media platforms. We have conceptualized this process in the *Model of Layers*, a multi-layered interaction model depicting the different interrelated media layers ranging from body to external environment or space (Fig. 1). NEMO allows interrelation between these layers, which is an essential condition for the independence of digital data from physical devices. This independence makes ubiquitous und pervasive communication and interaction possible.

Our educational foundation derives mainly from our understanding of an epistemological position that examines the process by which knowledge is socially constructed, known as *critical constructivism* [6], and from a pedagogical approach to organizing classroom activities into academic and social learning experiences, called *cooperative or collaborative learning* [7].

Our development of body- and space-related media is based on innovative scenarios and developed in a *participatory design process* [8] with intended future users. By this, user's expectations can be taken into account. Our research on innovative learning environments uses the methodology of *Design-Based Research* [9]. Our developments of analytical models and the co-design processes of applications with body- and space related interfaces evolve simultaneously as they are of equal importance.

Inspired by phenomenological media theories, as described for example by Marshall McLuhan [10, 11] and Vilém Flusser [12, 13], we understand ambient learning spaces as a digital augmentation of body and space.

The chapter will proceed with a description of the concept of ambient learning, referring to several layers, from ambient space to the body of man where the augmentation takes place. With key examples resulting from co-design development processes of the last decade, several applications focusing body- and space related learning environments are shown. After that, the Network Environment for Multimedia Objects (NEMO) will be described. Finally, we outline a scenario based on the development of NEMO. It creates a vivid picture of interdisciplinary learning supported by ambient learning spaces. Learners use media in different learning environments such as urban and rural space as well as more institutionalized spaces like schools. The framework supports collaborative learning and by identifying the specific user, the system fosters individualized learning on different physical user interfaces under a long-term perspective. A short outlook on future development and ambient learning spaces concludes our contribution.

2. The concept of Ambient Learning

The term *Ambient Learning* emerged during the last years and has not yet reached a state of common understanding. There is a project named *Ambient Learning* funded by the European Commission that deals with ambient, multimodal and context-sensitive lifelong learning [14]. Its idea is to offer citizens the opportunity to structure and define their personal training needs based on their locations and own interests. The provided eLearning service is easy to use and offered access independent from time and space, which can be seen as the main characteristic of the project.

Bomsdorf [15] conceives *Ambient Learning* as a combination of characteristics of ambient intelligence and requirements of learning paradigms. It is a permanent and self-directed process in which the learner's progress can be recorded on a regular schedule. A variety of learning content is provided on demand, which is also independent of time and location. Learning is embedded in usual situations that confront the learner with authentic problems. It offers the opportunity to interact with experts, tutors, or other learners and the learner gets the "right information at the right place in the right way".

Other authors like Bick [16] use the term more in the sense of extending Mobile eLearning. In contrast to *Mobile Learning*, where just mobile devices are used, *Ambient Learning* denotes new information and communication technology (ICT) embedded into the environment resulting in advanced e-learning scenarios. Not only mobile devices but also *Radio Frequency Identification* (RFID) or *Wireless Sensor Networks (WSN)* are used to embed new information and communication technology in the environment.

Next, Lyardet [17] characterizes ambient learning as the way people adopt technology in their everyday life and how technology changes the environment slightly. It is seen as the new realm of ubiquitous computing and the associated learning processes between people and *smart environments*.

Finally MIT's Tangible Media Group introduced the concept of ambient media [18, 19]. The concept evolved as a consequence of *ubiquitous computing* which pushed the computer into the background and hence made it invisible. This elicited a transition from graphical user interfaces (GUI) of desktop PCs to tangible user interfaces (TUIs) with the physical world serving as an interface. Furthermore, the background periphery is distinguished from the foreground which is in the center of the user's attention. In the foreground graspable media that are developed by connecting digital and physical objects allow the manipulation of foreground information. Tightly related, the notion of *ambient media* is crucial. They are created by coupling digital information to everyday physical objects and environments and therefore create augmented spaces. According to this conception, ambient media are complementary to tangible and graspable media that are manipulated in the foreground.

Our own understanding of *Ambient Learning Spaces* is distinct from the cited conceptions as far as

a) *Ambient Media* are not only understood as a peripheral media, as Ishii and Ullmer see them. However, we see their conception as the outer layer of an ambient learning space embedding the user. Tangible media and personalized media, such as mobile media, are subordinated.

b) *Ambient Learning* is not understood as a technological solution for "providing content" or "delivering material for training" in an individual or context sensitive way towards "in-situ learning" as Koelmel or Bomsdorf describe or towards "ambient instruction" as Lyardet describes. For us, the pedagogical shift from *learning goal oriented* to an *acquirement of competencies* [20] is a mayor key for *Ambient Learning Spaces*.

As a result, *Ambient Learning Spaces* are part of a mixed reality, interwoven with the web, which extend space and body. While tangible and ambient media extend action and communication space of a person who resides at a specific location, the use of mobile media extend human body at an arbitrary location. We define *Ambient Learning Spaces* as a combination of interrelated, but analytically different conceptual layers: ambient and tangible media digitally refer to the physical space around us, while mobile, wearable and implanted media digitally extend our body. The *Model of Media Layers* (Fig. 1) brings together all sorts of current media forms and depicts embedding our body and mind into onion-like layers of digital technology. Therefore *Ambient Learning Spaces* are extending our Lebensraum (anthroposphere) as well as our body. Technically, we implement this by the *Network Environment for Multimedia Objects (NEMO)*.

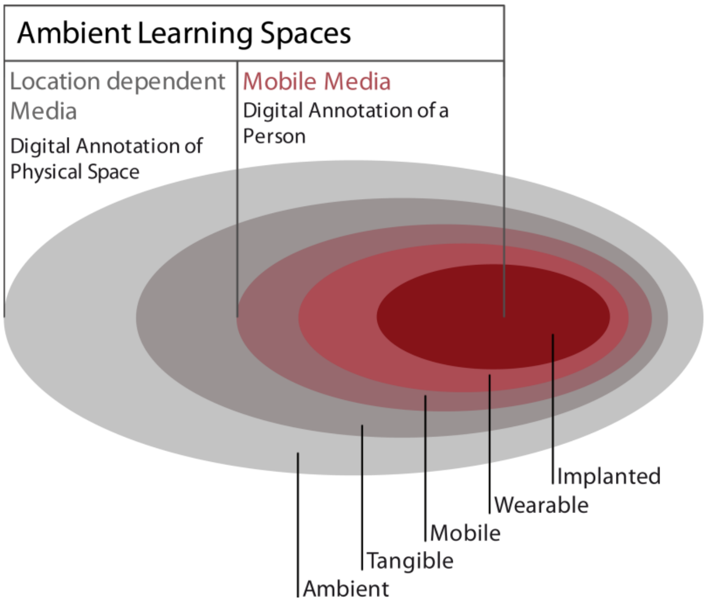

Fig. 1 Model of Media Layers

3. Applications focusing body- and space related learning

The next section illustrates some of our previous projects. Here different mixed reality learning environments have been established. We describe their development, use and some evaluations. The range of prototypical interactive systems implemented so far refer to all layers of our Model of Media Layers. We start by describing *Digital Fashion*, which is a project of creating wearables that were used in performance art. *Moles* and *InfoGrid* deal with mobile learning. The project *World of Dragons* implements motion detection by image processing and *Second Life vs. Real Life* deals with events in virtual environments elicited by gesture control on a physical stage and their projection into physical space. The *UniTable*, a multitouch table, can be used for learning games like *SpelLit*. The *Interactive School Wall*, consisting of several wall-mounted multitouch screens, enables groups of learners to restructure information cooperatively. Common to all projects are new forms of teaching and learning in different learning environments.

3.1 Digital Fashion

The example concerning wearables and thus the most inner layer we describe here of our *Model of Media Layers* is the class project *Digital Fashion* [21]. 10th graders programmed and created smart textiles, which they later used in self-produced video clips and performance art. The project intended to enable adolescents to develop experimentally new forms of communication and social interaction. Students were encouraged to engage with social critical aesthetics and their own identities in performance art as well as to reflect on patterns of communication and interaction of today's information society. They were enabled to make clothes more intelligent and give them an individual touch. Thus the surface of the body became an interactive interface by the wearables extending the possibilities of expressing their identity and personality.

During the project, students came into contact with different subjects. We intended to raise an understanding of clothes as a way of expressing cultural codes but also considering short-lived trends. Furthermore, students should get acquainted with microcontrollers, construct LED pads, program the LED matrix, initiate a mixed reality stage performance and acquire narratives in this context.

Digital Fashion was accompanied by teachers' education via teaching modules. These consisted of several workshops focusing on an interdisciplinary approach to use wearable media in pedagogical processes.[1]

An evaluation was carried out on students' attitudes towards clothing revealing especially an interest of girls for expressing emotions with the help of wearable media. Furthermore girls expressed greater satisfaction as well as motivation and took pride in the performance art indicating it is an approach especially suited for addressing girls' interests.

[1] The lessons as well as the workshops were conducted under the direction of Martina Ide, senior teacher at Carl-Jacob-Burckhardt-Gymnasium, Luebeck and teacher educator at the Institute for Quality Development of Schools in Schleswig-Holstein, Germany.

3.2 Moles

The *Mobile Learning Exploration System* (*Moles*) [22] enables learners to generate content for mobile learning situations as part of curriculum-based formal learning. The *Moles Creator* is a web-based application that works on a computer which generates content for Multimedia Interactive Assignments (MIA). MIAs follow a didactic approach in which questions are defined and information collected by the students themselves while they organize excursions and mobile learning games. With the *Moles Player* a web-based application for modern cellular phones (smartphones) MIAs can be executed.

During mobile learning with the Moles Player, learners answer questions in context of physically rich experiences at the respective place, e.g. at a habitat, a company, urban space, museum etc. The use of MIAs includes recording of observations and findings. An integrated chat function facilitates the cooperative work independent of the location.

In the near future the applications will allow the localization of players or learners by GPS. Further it will be possible to show their geographic position on other devices, e.g. the *Interactive School Wall* (see 3.8). Also other digital devices can be used in this context, such as sensors and measurement instruments. The collected information can be used during the game or later by browser-based applications.

An example for the use of *Moles* is *Time Travelers to the Medieval* [23]. In this project 8th grade students participated in a mobile learning game about life during the Middle Ages. They prepared MIAs and visited special places in the historic city of Luebeck, e.g. a pharmacy and a museum. Back in School, they discussed the annotations they made during their excursion.[2]

3.3 InfoGrid

The *InfoGrid* system is an interactive web-based platform which is used predominantly on users' personal smartphones [24]. Experiences occurring in the physical space (e.g. city walk, museum visit) are enriched by digital information. The system allows interaction with multimedia objects (texts, videos, audio files, photos) related to the context of specific places or artifacts and the interaction with other users.

An important aspect is the localization of individual users that allows an individualized provision of information, for example hypermedia narratives (stories) [25], specific presentation of multimedia objects on other media platforms as well as the communication with other users of the system.

Every user has access to object- or location-dependent information via the smart phone without the necessity of intricate downloads or installation processes. A mobile phone with an integrated camera is required, because the respective information is received by taking a photo of the barcode (QR-codes). For this purpose a small application has to be installed. Also, the individual provision of user data is only possible if the person has registered once in the system, indicating his date of birth, sex, and language preference. This can be done earlier on the website of *InfoGrid*, or immediately before use by means of the smartphone.

An example of the use of *InfoGrid* is the serious game[3] *The Whales of the Baltic Sea*. Children and adolescents may begin at any point of information in the *Museum of Nature and Environment* of Luebeck in northern Germany. For example a female user follows a story of a girl who, while sailing on a sailboat, encounters porpoises[4] for the first time. The girl becomes increasingly interested and committed for their protection until she becomes a marine biologist.

3.3 Your Food is Your Mood

An example of the use of *Barcode-Player* represents the teaching project *Your Food is Your Mood* [26, 27]. 5th graders learn about relations between nutrition, their bodies and the sense of well-being. In an interdisciplinary learning project (biology and arts), students learn how to express and reflect upon their knowledge about the biology of food and mood.

They build an interactive hypervideo installation with one computer and a barcode scanner with four computers and video projectors around a cubical tent. Each tent wall serves as a rear projection for the students' self-made video clips. These clips are controlled by a tangible user interface (TUI).

A TUI is generated by barcodes on physical objects (sausage, apple, water bottle, soft drink, etc.) read out by the *Barcode-Player* running on a PC or laptop, that is attached to a barcode scanner. The application controls the installation and determines which video has to be played on which video projector at a certain time.

The subject of diet, nutrition and digestion in their biology curriculum is linked with various forms of expression developed in their art classes. Throughout this project, the children are able to reflect upon the aesthetics and scientific facts about their personal eating habits. In the artistic environment of *Your Food is Your Mood* the computer disappears[5] into a box with keyboard and screen [28, 3]. In the learning scenario, the computer is almost invisible to the user because the children created the interactive multi-sensory experience in form of an immersive installation. Essentially by incorporating objects as physical icons, called phycons, the children break down the physical boundaries of the computer and map its virtual content back into their physical world.

[2] The lessons were conducted under the direction of Martina Ide, senior teacher at Carl-Jacob-Burckhardt-Gymnasium, Luebeck, Germany.
[3] A *serious game* is a game designed for a primary purpose other than pure entertainment.
[4] Porpoises, also called mereswine, are small cetaceans, akin to dolphins.
[5] In the sense, that you can't see the computer anymore.

An evaluation shows that major long term learning effects occurs when children build a tangible interface and design an interactive installation, which creates a relation between their ideas and their physical world.

3.4 Second Life vs. Real Life

In the project *Second Life vs. Real Life* a special learning space was created by intertwining physical and digital reality [29]. Second Life (SL) provides a wide range of possibilities to create and develop one's own virtual world by designing and programming individual objects.[6]

A course program for 12th grade students was created. Strategies from media art gave new impulses concerning the development of new ideas and new modes of behavior. The young people had the chance to reflect upon their behavior within the physical world, because daily experiences were incorporated into the digital world. The students transposed their real world clothing to digital, as well as digital elements from SL into the physical space. They evaluated the function and importance of clothing for their own identity. To make this possible, we arranged reflection into the classroom and a video stream projection within SL, where students encountered other students as avatars and could talk to them. However, transferring the digital projection in the physical space did not create an effect of digital immersion. Instead, the situation was experienced as augmented physical space.

Our objective was to broaden social, ethical and professional competences by offering more complex and richer forms of interaction. While oscillating between the two “worlds” in a creative process, divergent patterns of interpretation and behavior gave the opportunity for self-directed and playful experiences. We were able to show new ways of creating communication and interaction spaces, bridging the gap between the physical and digital 3-dimensional space. We created an innovative learning arrangement that supported multi-codal and multi-modal learning, self-directed research and exploration as well as collaborative, topic-oriented, subject-relating learning contextualized according to real, everyday needs.

3.5 SpelLit

SpelLit is an application, which fosters literacy skills at elementary schools. For the development of our educational software, traditional concepts of learning have been adapted to fit a multitouch table, called the *UniTable*. While observing children at work in school, it can often be seen that they gather around tables in groups of four or more and work together on the same topic. Learning in groups and helping each other fosters teamwork and is a very important aspect, as one of the fundamentals of human beings is the interconnection and collaborative learning with one another [30]. Multitouch tables create an environment that supports collaboration [31] unlike a conventional computer with only one child sitting in front, because these tables are more seamlessly integrated in the environment and seem to reduce the barrier between users and technology. They improve multimodal learning by addressing multiple senses, because additionally to hearing and seeing, it is possible for children to "touch" everything they see and by this interact with objects on their desktop. Thus, the probability, that children really understand the topic at hand increases [32, 33]. This new learning environment was chosen as it provides a simpler and more natural interaction for children. It refers to known analogue learning habits in schools but offers manifold possibilities of computers.

The *SpelLit* software was built on top of this educational multitouch system. We took the phonics-letter-chart of Reichen [34]. We did not just transfer the chart to a PC but combined it with another educational approach of Freinet and adapted it to the new capabilities that multitouch tables offer. The concept of Reichen has similarities to the Freinet printing press [35]. They both encourage children to learn in an independent way and to create words or even sentences on their own. In contrast to Reichen, Freinet offers more active educational elements like the grasping of letter stamps for his printing press and the process of actual printing, which plays an important role in the educational development for small children. We wanted to transfer both ideas to the multitouch table in order to try a new approach to teaching literacy. By combining visual with haptic and auditory elements the greatest possible effect in multisensory learning can be achieved.

At the first stage of the *SpelLit* game, ten pictures are presented randomly on the screen of the *UniTable*. The children can take a closer look and choose a picture the name of which they want to spell. At the second stage all non-activated pictures disappear and a set of initial sounds comes up in the middle of the screen. The children are supposed to write the word of the presented pictures with the help of the initial sounds. By pressing one of the letters, an initial sound gets read out. By this, the children can build a mental association between letter, sound and picture. All residing pictures have a grid where the initial sound elements can be placed. If the grid of a picture is completely filled with initial sound elements, the correctness of the written word is verified automatically. Then, the word can be corrected if needed.

The *SpelLit* software in combination with the *UniTable* contributes to the motivation to learn, as the interaction is easily graspable and much fun for children. The closed system with automatic correction also fosters collaboration, which results in children learning from children without the need of a supervisor to interact frequently.

[6] The lessons were conducted under the direction of Martina Ide, senior teacher at Carl-Jacob-Burckhardt-Gymnasium, Luebeck, Germany.

As the UniTable is used by students of different age and has been especially constructed in respect of size and height. The height is adjustable in order to suit small children as well as older students and the size of the display is kept rather small so that everything is within reach.

3.7 World of Dragons

The *World of Dragons*[7] aimed at fostering 3rd grade students' ability to think abstractly and in a structured way [36]. They developed an interactive music performance based on a self-written story about the everyday life of a dragon. This happened in cross-disciplinary lessons taking the subjects art, free dance and computer science into account. The students designed stage props that triggered animations on the stage during the performance. The LEGO software *Vision Command* defined which events were elicited by the stage props. During rehearsals, the students could improve their sensitivity for music and their confidence in their physical skills. They developed small animations and music for the performance as well as sound elements. Of course the most exciting part was a public performance in front of an audience.

These young students improved their computer skills and learned to create animations and to program behavior sequences for picture recognition. For this activity an iconic program code was coupled to multi-sensual experience and design. Thereby the children learned successfully about a quite abstract topic and to use media creatively and constructively.

For the performance, real world and virtual world were intertwined in two steps. There were real elements of the scenery such as trees, volcanic rocks and watering cans but also an interactive stage that had elements of virtual rooms by a projection onto stage. Thus the real world was the interface to the virtual world.

3.8 Interactive School Wall

The *Interactive School Wall* (ISW)[8] consists of currently four wall-mounted multitouch displays [37]. It is located in the entrance hall of a secondary school in northern Germany. It can be used in regular classes in several ways but its main function is to serve as a platform for presentation and interaction for informal learning. Groups of learners can structure and arrange information supported by visual aids.

Typical applications are for example a *Semantic Map* and an *Interactive Timeline*. In this way the students add media that they designed in their classes. These come from the fields of arts and culture, science and technology, politics and social studies.

This can be seen as enhancement of co-operative learning and constructing transferable knowledge. Apart from its multifaceted range of applications it aims at supporting learning in an active and interactive way. In this way explorative learning could be motivated too.

First step towards a usage in formal education is exemplified by the use of ISW as part of a pervasive game with Moles. The ISW can also act as part of an interactive stage, because it has four powerful zoom and swivel cameras. Via image processing the playback functions of audio-visual media at the ISW can be controlled.

4. The Network Environment for Multimedia Objects (NEMO)

The idea of *Ambient Learning Spaces* is based on a concept where digital data and information is independent from specific physical devices as it had been pointed out at the end of the first section with examples of several applications. In order to realize these scenarios we are implementing a platform called *NEMO* (*Network Environment for Multimedia Objects*). NEMO is a new kind of media repository, which provides the user with access to contextualized, personalized, semantically enriched and device-specific *NEMO Multimedia Objects (NMOs)* [38]. These NMOs are containers for metadata and media objects, which consist of media entities like videos, audio files, texts or 3D objects. These media hold different kinds of meta-information like authorship, access rights, content descriptions, semantic annotations, location data, or device-specific information. These data make the NMOs much “richer” than most multimedia data, which allows deducing dependencies between NMOs or retrieving user- and location-related information.

NEMO Multimedia Objects can be accessed and manipulated from a variety of computing platforms and interaction devices, such as mobile phones, multitouch tables, desktop computers and interactive whiteboards. NEMO facilitates the communication and exchange of data between those devices. Users are able to work on the same set of data, while making use of the distinct advantages and capabilities of the current computing device they use. For example, en route, one can survey objects or make small annotations on a mobile device, while at home at the desktop computer, complex and optimized tools can be used on the same object for further processing. As NEMO knows which device and device type it is communicating with, it is able to adjust the content of the NMOs to adjust to the capabilities of the different

[7] The lessons were conducted under the direction of Barbara Brökemeier, teacher at the primary school Schule Lauerholz, Luebeck, Germany.
[8] The concept was primarily developed by Martina Ide, senior teacher at the secondary school Carl-Jacob-Buckhardt-Gymnasium, Luebeck, Germany.

devices. 3D-displays for example automatically get a three-dimensional instead of a two-dimensional data of the same object, as far as available. Multitouch tables need information about position, rotation and scale of an image, while cellular phones just need basic and low-resolution images. Desktop computers will get larger sized versions of videos and pictures or more additional information of the same object than mobile devices because of their surplus concerning resolution and display size.

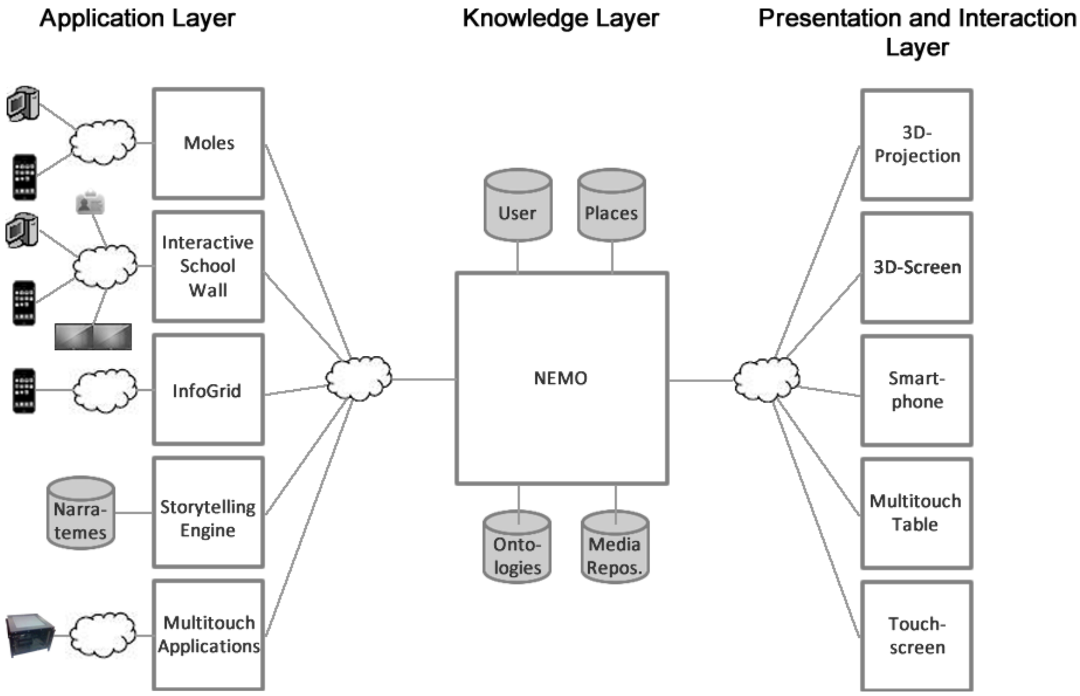

Fig. 2 NEMO Framework with different Applications and Interaction Devices

The NEMO system is basically split into three different layers (Fig. 2). The middle part consists of the knowledge-layer, which represents the back end of NEMO. It is the main part where information and media is gathered and stored. On the right side there is the presentation and interaction layer with all NEMO I/O-clients, representing the front end of the system. These clients offer basic functionality for graphical representation, interaction and manipulation of NMOs and other multimedia content. The style of interaction depends on particular capabilities of the used devices like multitouch-tables, cellular phones or 3D-systems. On the left side resides the application layer with applications like Moles, InfoGrid and the ISW. The application services are responsible for the creation and further processing of the NMOs and provide information about possible semantic relations. In addition to the basic functionality of the presentation layer, the application services offer richer and application specific interaction methods. Existing applications can be connected to the NEMO system and by that extend their field of use. Through this it is possible to realize complex learning scenarios where different didactical body- and space-related media complement each other in a reasonable way.

This architecture makes it possible for users to work to high extent device-independent. They can work alone or collaborate with others on the same data from different locations and add, exchange, or enrich objects. This flexibility in presenting and interacting with content changes the way users may handle their media and is one of the main aspects of *Ambient Learning Spaces* as we defined it earlier (Fig. 3).

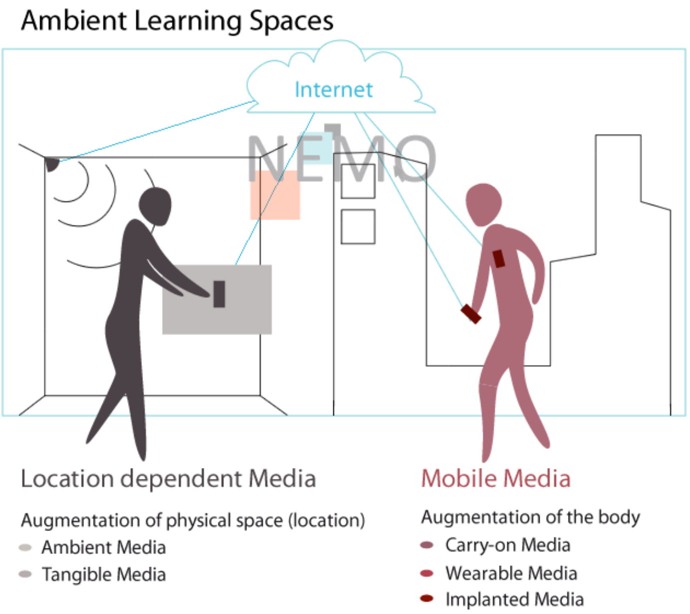

Fig. 3 NEMO connecting the Media Layers in Ambient Learning Spaces

5. Scenario

In this section, we present a scenario that shall give a vivid picture of an innovative learning scenario. Its objective is to support students' collaborative and interdisciplinary learning in flexible learning spaces.

5.1 Scenario Summary

In this scenario, students in a complex learning situation are supported by connected media. They collect information in different learning spaces in- and outside their school environment - e.g. at the office for environmental protection or the office for the promotion of tourism and outdoors in nature - and include them in a collaborative learning process. Data and information generated at respective locations, i.e. interviews recorded with the help of mobile phones, are directly transmitted to NEMO. A chat function allows a permanent communication between students and teachers. After that, the collected information is retrieved by a medium for presentational purposes (e.g. the ISW) at school. It is then organized and discussed cooperatively with other students.

A subsequent visit to a museum builds on the acquired knowledge and deepens it in the course of a learning game. In the game, the students follow arranged learning paths which are adapted to the individual student. The system draws on information about the users' gender, age, interests etc. This provides the students with suitable assistance and takes their individual interests into account.

5.2 Objective

The aim of the scenario is to create a multidisciplinary learning situation, in which the learning process is supported by connected media. Today, multidisciplinary learning is a substantial part of the school curricula in many countries. The idea of competence-oriented teaching emerged around the turn of the millennium as a reaction to a shift in pedagogical approaches. As such, teaching is increasingly understood in terms of enhancing a wide range of competences and less as the achievement of strict learning goals. The scenario describes how a learning situation can be enriched by ambient media in order to support learning processes. A main characteristic of our media model are that the same digital objects can be displayed and annotated on different media platforms. The learning scenario described in this example deals with the marine ecology of the Baltic Sea. Economic, cultural and ethical topics are combined in a critical, intrinsically motivated and collaborative way, and set in relation with the students' own life environment and experiences. The utilization of interconnected interactive media shall foster systemic thinking (i.e. thinking in high complexity), allowing students to consciously reflect and adapt their personal way of acting.

5.3 Scenario

Students of a 7th grade work on their main subject the Baltic Sea during interdisciplinary classes. They occupy themselves with the natural bases of life and their conservation as well as possible changes of their own action in the face of anthropogenic influences on the marine habitat and the repercussions for man in the context of the subjects of geography and biology.

First, the students carry out some research on the web, e.g. on data of the scientific measurement station “Fehmarn Belt” of the German Maritime and Hydrographic Agency. After that, the students create an Multimedia Interactive Assignment (MIA), which they can use on mobile phones during different excursions outside of school (e.g. at a fishing company, office for the promotion of tourism, office for environmental protection, operators of harbors or a pier at the Baltic Sea). They do this with the aid of the web-based Mobile Learning Exploration System (Moles). The MIA can be displayed in the browser of their mobile phones and the forms can be filled in. They also structure the students' activities while they are investigating at learning locations outside of school. The students take measurements with the help of a mobile laboratory near a pier and add the collected data via their mobile phones to a database. They can conduct an interview at the office for environmental protection and record it with the camera of the mobile phone. The interview is saved via web-based technology at once. Using the chat function they keep in contact with the other students and their teachers throughout all these activities.

The MIAs prepared by the students before the excursion and the newly created multimedia objects (e.g. texts, videos, audio files, photos, etc.) are stored in the NEMO system. The students can authenticate through a standard user management system, to which NEMO is connected to. Viable solutions are simple singular input of username and password or tokens which can be read by the students' mobile phones.

On another day, the students assemble in front of the Interactive School Wall (ISW) in the foyer of the school. The ISW consists of several multitouch displays, which have access to a web server. The students interact with the wall in small groups, authenticate through an integrated RFID-reader and recall the information they collected the day before. In a discussion with the other students, the group arranges the information in suitable patterns.

The students' personalized RFID-tokens are assigned to individual NEMO users. The user management system enables users to log in from different devices and get access to the multimedia objects stored in NEMO, which they created before. Furthermore, they can work with objects which were sent to them personally or to groups they are members of. It is possible to use the semantic search of NEMO to get access to more related NEMO objects.

This way, a wide range of different data is available to the students: information stemming from freely accessible sources, materials provided by the teachers, the contents of the MIAs as well as texts, pictures, photos, videos etc. produced during individual and collaborative research.

The ISW enables students to navigate through a complex information space, to structure it and sort and annotate the used data. Therefore, they get access to the NEMO objects they want to work with. These can be replaced and grouped on the large *multitouch displays*. An important advantage of the size of the ISW is that it allows a larger group to work on the structure of the data at the same time. The objects can be moved from one screen to another where other students can work with them. Furthermore, the size in which objects are displayed is large enough to activate discussions among the groups.

On the following day, the students make a visit to the Museum of Nature and Environment. There they enter the permanent exhibition “In the empire of the Aquarius”, where they can vividly experience a multitude of exhibits concerning the Baltic Sea.

The students can log in a learning game by taking photos of QR-codes which are displayed at numerous places in the museum. This learning game is realized by the web-based application InfoGrid. In the course of the learning game, they adopt the position of a researcher. InfoGrid serves them with personalized information appropriate for their age and matching the exhibits. The students are guided on individual narrative paths through the museum to different exhibits and so they are evenly distributed across the museum. The system records time and quality of the inspection of the exhibits by the learners' input into the system.

A central user management system, which NEMO is connected to, plays the central role for identification and authentification, while NEMO acts as a provider of the multimedia objects as mentioned previously.

Using InfoGrid, physical objects can be enriched with multimedia objects. This is done by adding QR-codes to the different objects or places. The users can take photographs of the QR-codes with their mobile phones and as a consequence InfoGrid provides them with information regarding the respective location.

At the same time, these pieces of information are contextualized, because the students' identity can be determined by the smartphone they use. By the narration system of InfoGrid it is possible to accord different information to different students considering their various roles, previous knowledge and gender.

Another advantage is that students can be equally distributed across the museum and its exhibits. InfoGrid determines the order in which the different places are visited and also the sequence in which the multimedia objects are accessed and physical objects are investigated. In this aspect InfoGrid is different from Moles where the users decide themselves which path they want to take through the physical world and the postgeographic space.

Students log into the system at the various locations (by taking photos of the QR-codes) and thus the duration of interaction at the respective places can be recorded. Hypotheses about the nature of the interaction can be built on the (presumably) intensity of work on the multimedia objects, although there is enormous uncertainty inherent in interpreting the intensity of the students' activity and the effect of incidental disturbances during that period.

On the same day, another attraction is waiting for the students at the museum. In small groups ranging from at least four to a maximum of eight students the acquired knowledge and abilities can be applied practically in a simulation model.

At a multitouch table, four pairs of students can play a complex simulation that demonstrates new relations between the exhibits to the students. The experimental game confronts the students with a problem that has to be solved in cooperation. What is discussed here, are the complex relations between the economic region (fishing facing the problems of gillnets, tourism and events such as speedboat races etc.) glocal environmental factors (climate, water temperatures, changes of the water quality etc.) and the effects on flora and fauna (microorganisms, aquatic plants, fish, birds and marine mammals). The students can try out different strategies to tackle the problems. In the game, the students represent the different interest groups, e.g. the position of fisheries or the Environment Agency.

Having information about the students' former activities from its connection with the systems Moles and InfoGrid, the narrative component together with the user management component, which are connected to NEMO know which aspects of the exhibition were visited before or which role the students had as researchers in the learning game in the museum.

The students' assignments to the different roles in the simulation are based on the following principle: the students who visited the fishermen can represent the interests of fisheries and those who went to the Environment Agency on their excursion represent the environmental protection. At the same time, the multimedia objects generated or extended by the users are used to adjust the game to the players. So the generic photo of a fisherman can be replaced with a real photo taken by a student.

Back at school, the students extend the work on their school project including the results of the experimental game that are provided by NEMO.

The multimedia objects that were created, extended and annotated throughout the learning unit are related to the educational material at school. A documentation of the process can be conducted by the students themselves in cooperation with their teachers. Thus the students' access can be extended from generic multimedia objects to their own objects, which allows a stronger identification with the subject. An enactive [9] acquisition of information and competences is supported as it is described in theories of autonomous and collaborative, body and space related learning, and in the presented model of ambient learning.

The portrayed scenario is refined as explained above in collaboration with schools and museums and constitutes a realistic learning situation. The technical components are to some degree already implemented (Moles and InfoGrid) but not completely (NEMO, narration system). Our main concern is the inclusion of technical solutions into real learning situations and so we emphasize their continuous evaluation in the pedagogical context.

5.3 Further scenarios

The immediate objective of our research and development of prototype systems is to connect more and more applications that make up the entirety of the *Media Layers*, where NEMO is the central semantic storage. To this end, we are currently working with several other scenarios. For example, one in which the focus lies on *performative processes* regarding composite subjects of *art*, *music*, *dance*, *languages*, *drama*, and *hypervideo*. Here, the 3D gesture recognition via *Microsoft Kinect* plays an important part. Also *Hypervid*, our web-based hypervideo creator [39], will be used. It seeks a strong space- and body-related control of interactive media.

Another scenario deals with culture and history in the specific context of architecture. Children and youth take part in a serious pervasive game, where they personify people from a merchant family in the 16th Century. With the help of an augmented reality application on their smartphones they can learn about different aspects in the life of a family, living in the urban areas of the historic old town of Lübeck in northern Germany.

6. Summary and Outlook

In this contribution we provided an overview of our research on *Mixed Reality Learning Environments*. The pedagogical background of critical constructivism as well as the theoretical framework of *Design-Based Research* has been explained. We introduced our conception of *Ambient Learning Spaces* and highlighted their special use cases. Our conception of *Ambient Learning Spaces* is distinct from others as far as we conceive ambient media as the outer layer of an ambient learning space and ambient learning as the experience-based and contextualized acquirement of competencies rather than simple goal-orientated learning. In the *Model of Media Layers* we described the conception of the layer structure in more detail. We further illustrated some of our former projects that are supposed to encourage adoption of innovative learning spaces. The crucial aspect of our research is the iterative implementation of the integrative platform NEMO together with the applications outlined, by which the use of digital data will be widely

[9] *Enactive* knowledge unfolds through bodily action. It is constructed on motor skills, i.e. manipulating objects.

independent from physical devices. Finally we presented an innovative learning scenario in order to emphasize the various capabilities and opportunities of ambient learning spaces. We think that the borders between media layers will vanish by overlapping and interconnecting them to make new forms of learning possible, as we described in the central scenario, where body- and space-related web-based media will play a significant role.

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