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Ubiquitous support for lifelong leaners with mobile technology

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General Introduction[1]

The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it.

(Mark Weiser, 1991)

In Mark Weiser's vision of the computer for the 21st century, computers should be the next technology becoming "an integral, invisible part of people's lives". Basically, the computers would be seamlessly integrated in our life, accessible and connected via networks or somewhere around us "imbedded in walls, chairs, clothing, light switches, cars – in everything" (Weiser, 1991). He described this as ubiquitous computing "characterized by the connection of things in the world with computation". And where are we now? Well, his vision is almost the reality. Although computers are not yet fully seamlessly integrated in this world, they are already highly interconnected and interwoven with our daily practice. Along with the growing connectivity, getting mobile is the trend of our time and can be seen as one intermediate stage towards ubiquitous computing.

Following these trends, it is expected that the number of mobile-connected devices will exceed the number of people on earth by the end of this year (Cisco, 2013). In the next stage more and more of these devices might indeed become ubiquitous – not only with and close to the people but blended into the environment. Ambient displays are one possible technical implementation within this next stage. The term originates from advertising, characterising appliances such as advertising pillars or billboards. Looking at linguistic definitions, the adjective ambient is described as "relating to the immediate surroundings of something" or "relating to or denoting advertising that makes use of sites or objects other than the established media" (Oxford Dictionaries, 2010). The noun display is among others described as "a collection of objects arranged for public viewing", but also as "an electronic device for the visual presentation of data or images" (Oxford Dictionaries, 2010).

[1] This chapter incorporates abstracts and introductions from several publications.

Inspired by Weiser's vision, Wisneski et al. (1998) introduced ambient displays in the context of ubiquitous computing as "new approach to interfacing people with online digital information", whereas the "information is moved off the screen into the physical environment, manifesting itself as subtle changes in form, movement, sound, colour, smell, temperature, or light". Instead of demanding attention the approach exploits the human peripheral perception capabilities. The displays situated and interacting in the close proximity are an addition to existing personal interfaces in the foreground, while the user attention can always move from one to the other and back.

The described interaction approach is not new. Looking around one can find several examples that are in line with the given definition. Just take a look at the cover of this thesis. What you see at a first glance is a number of billboards trying to capture the attention of the people passing by. They all try to convey a particular message in a visually appealing way using mainly colour and light. Some also add movement and sound to become even more intrusive. These displays live in the periphery of attention. Although they are designed to make it almost impossible to ignore them, it is possible to keep them out of the focus. Still they are not completely in line with the original definition.

Looking again at the cover, you might find another more unobtrusive ambient display - a traffic light. Already in 1868 a first prototype was installed at a busy intersection in London. The idea was to assist police officers in directing traffic, mainly consisting of pedestrians and horse-drawn vehicles. The manually operated device combined a semaphore with moveable arms and a gas lantern showing red light to signal "Stop" and green light to signal "Caution". With the invention of the automobile, the traffic got heavier and the idea spread. Later on the lights became electric, the semaphores were abandoned, and their operation was automated. Ever since the way of signalling remained more or less the same: a red light indicates to stop, a green light indicates the possibility to cross, and occasionally a yellow or orange light indicates (as state in-between) either to prepare for the one or the other state.

Back to the original definition also traffic lights try to convey a message visually using again mainly colour and light. They live in the periphery and use subtle changes between the various states to capture attention and get in the focus when necessary. This functionality and the contained visual metaphor have even become ubiquitous in a sense that the concept is also used in different contexts, such as food labelling. Consequently traffic lights can be seen as successful ambient display instances following the definition of Wisneski et al. (1998) with the exception that they do not present or at least symbolise online digital information. Adding up this peculiarity it becomes apparent that there might be some merit in applying the concept also in a learning context.

> *The people are fundamentally, inherently mobile – they move around; they never, never would want to be leashed tight to a desk or to their home or to their office if they have a choice.*
>
> (Martin Cooper, 2005)

As Martin Cooper, the inventor of the cell phone, framed it, mobility is one of the basic human needs that influences all aspects of life. Accordingly, the era of mobile and ubiquitous computing challenges the way we learn with computers. Computers as learning technology disappear from the main focus of a learner's attention and become means to an end. Instead of acting as yet another disrupting threshold in the learning process they become integrated unobtrusive facilitators. Again getting mobile is the major trend. Mobile learning focuses on learning support across contexts and learning with mobile devices. Arguably the mobile learner of today is not one that solely uses mobiles to access traditional learning materials – rather it's a learner who is mobile and moves through different environments and occasionally stumbles upon traditional or newly designed learning opportunities and activities. Learning in this world is mostly informal, happens accidentally and in situ, and is highly contextualised. Consequently ubiquitous learning not only enables learning across context, but also facilitates and exploits the mobility of the learners instead of the technology.

Following this approach the ability to deliver contextualised and personalised information in authentic situations fosters ambient displays as an instrument for learning. Up until now this has not been a major research focus. The design of ambient displays for learning proves to be difficult, as the technical implementations as well as the underlying instructional principles are still immature. These gaps are the starting point for this thesis – presenting the results of the conducted research and development of ambient learning displays.

Outline of the thesis

The thesis is structured into three parts: theoretical foundations, formative studies, and empirical findings. An elaborated conceptual framework and an extensive literature review explore the research field and lay the foundation for further research. **Chapter 1** starts with outlining the vision of ambient learning displays. With a focus on the situated support of informal and non-formal learning scenarios in ubiquitous learning environments learners should be enabled to view, access, and interact with contextualised digital content presented in an ambient way.

The vision is based on a detailed exploration of the characteristics of ubiquitous learning and a deduction of informational, interactional, and instructional aspects to focus on. Towards the vision essential research questions and objectives as well as a conceptual framework that acquires, channels, and delivers the information framed in the learning process are presented. To deliver scientific insights into the authentic learning support in informal and non-formal learning situations and to provide suggestions for the future design of ambient systems for learning the chapter concludes with a research agenda proposing the research project including a discussion of related issues and challenges.

Chapter 2 then presents results from a recent literature review on ambient displays. While the main background of the authors is education and technology-enhanced learning, the chapter starts more generic with a broader view on ambient displays and their interactional, instructional, and informational characteristics. Beside depicting characteristics and classifying prototypical designs, the chapter also sheds light on the actual use of the covered ambient displays, their application context and addressed domains as well as the type of studies conducted, including the used methodologies and evaluation approaches to measure their effectiveness and impact. The chapter concludes with a discussion of the presented results emphasising the derived implications for the user when interacting with ambient displays.

The review continues in **Chapter 3** analysing work in the research field of ambient display with a focus on the use of ambient displays for situational awareness, feedback and learning. The purpose was to assess the state-of-the-art of the use of ambient displays with an explicit or implicit learning purpose and the possible classification of respective prototypes on the basis of a presented framework. This framework is comprised of theories around the educational concepts of situational awareness and feedback as well as design dimensions of ambient displays. The chapter presents results of recent empirical studies within this field as well as developed prototypes with a focus on their design and instructional capabilities when providing feedback.

Several formative studies inform the theoretical work as well as the design and development from different perspectives. **Chapter 4** first of all introduces concept mapping as a structured participative conceptualisation approach to identify clusters of ideas and opinions generated by experts within the domain of mobile learning. Utilising this approach, the chapter aims to contribute to a definition of key domain characteristics by identifying the main educational concepts related to mobile learning. A short literature review points out the attempts to find a clear definition for mobile learning as well as the different perspectives taken. Based on this an explorative study was conducted, focusing on the educational problems that underpin the expectations on mobile learning. Using the concept mapping approach, the study identified these educational problems and the related domain concepts.

Chapter 5 presents a project that sets up to make energy consumption data visible and accessible to employees by providing dynamic situated feedback at the workplace. Therefore, a supporting infrastructure as well as two example applications have been implemented and evaluated. The resulting prototype fosters a ubiquitous learning process among the employees with the goal to change their consumption behaviour as well as their attitudes towards energy conservation. The chapter presents the approach, the requirements, the infrastructure and applications, as well as the evaluation results of the conducted informative study, comparative study, user evaluation, and design study.

A pervasive game to increase the environmental awareness and pro-environmental behaviour at the workplace is presented in **Chapter 6**. Based on a discussion of the theoretical background and related work the game design and game elements are introduced. Furthermore, the results of a formative evaluation study are presented and discussed. The results show that incentive mechanisms are less important than challenging game components that involve employees in proposing solutions for energy conservation at the workplace. Conclusions are drawn for future games and energy conservation activities at the workplace.

Chapter 7 summarises the main constituents of a lecture series on the use of ambient displays for learning and a participatory design study conducted during two consecutive lecture sessions. The results show a variety of usable ambient display types, possible learning scenarios, and specific design proposals towards ambient learning displays.

Following up the theoretical work and the formative studies, empirical studies then evaluated ambient learning display prototypes. The first study presented in **Chapter 8** reports an intervention to initiate environmental learning and facilitate pro-environmental behaviour. The purpose was to examine the impact of ambient learning displays on energy consumption and conservation at the workplace, more specifically the evaluation of learning outcome and behaviour change. Using a quasi-experimental design, the study was conducted among employees working at a university campus. For the experimental treatments, ambient learning display prototypes were varied on two design dimensions, namely representational fidelity and notification level.

Related to this **Chapter 9** then presents an approach to better understand the interaction between users and ambient displays and the evaluation thereof. The purpose of the study was to examine the user attention towards ambient displays as well as the influence of different display designs in a combined approach using quantitative attention data as well as qualitative assessment methods. The study originates from the previous intervention using the same quasi-experimental design, but with a different research objective.

Finally the second study presented in **Chapter 10** reports an intervention to investigate identified research challenges on the evaluation and use of ambient displays in a learning context with the objective to gain insights into the interplay between display design, user attention, and knowledge acquisition. The main research questions were whether an attention-aware display design can capture the user's focus of attention and whether this has an influence on the knowledge gain. A display prototype corresponding to the main ambient display characteristics was designed, applied in a controlled authentic setting, and evaluated accordingly. The prototype conveyed indexical information and was enhanced with a custom-built sensor to measure user attention and trigger interruptive notifications. The study was conducted among employees working at a university campus. Using an experimental research design, a treatment group exposed to an attention-aware display design was compared to a control group.

The thesis concludes with a **General Discussion** reviewing all reported results and their practical implications, general limitations of the conducted research, as well as future research perspectives.

Part I

Theoretical Foundations

Chapter 1

Thinking outside the box: A vision of ambient learning displays

The first part of the thesis looks into the theoretical foundations for the following research. This chapter starts with outlining the vision of ambient learning displays and elaborating on a conceptual framework. Relevant research findings, models, design dimensions, and taxonomies are examined to deduce informational, interactional, and instructional aspects to focus on. The resulting conceptual framework consists of parts dedicated to user and context data acquisition, channelling of information, and delivery of contextualised information framed in a learning process. The chapter concludes with a research agenda.

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1.1 Introduction and background

Within the knowledge society the constant update of knowledge and competences of individuals is becoming a necessity to solve some urgent problems of the 21st century. From a lifelong learning perspective users should be enabled to participate in training and learning activities throughout their lifetime, be it within formal educational programs or non-formal respectively informal educational activities (Smith, 2009). We differentiate between educational activities conducted in the context of an educational institution (formal learning) and activities, which are planned and conducted outside of educational institutions and curriculums (non-formal) or even activities which are unplanned or accidental (informal learning). At the same time the technical prospects are changing. The amount of mobile consumer devices is rapidly growing and predicted to be ten times higher than the amount of stationary devices (Morgan Stanley, 2009). Notably the used technology becomes also embedded into the physical environment providing a new digital layer that supplements existing facilities and architectures, ranging from automobiles, over living rooms, up to buildings that become smart. Furthermore, the mobile internet is adopted much faster than the traditional desktop internet. In a rather short period of time after launching respective mobile services attracted already more users than desktop services did in a comparable period and the mobile data traffic is increasing continuously (Morgan Stanley, 2009).

This growing adoption of mobile technologies accompanied with ubiquitous connectivity as well as the increasing pervasiveness of information technology are changing the conditions for lifelong learning. Especially informal learning is becoming more and more prominent in mobile learning approaches (Ally, 2009). While rethinking the relationship of environment, technology, and learning, the promises of mobile and ubiquitous learning need to be explored to build a bridge between different contexts and situations learners are operating in. This is strongly related to authentic learning theories and situated learning. Authentic learning "allows students to explore, discover, discuss, and meaningfully construct concepts and relationships in contexts that involve real-world problems and projects that are relevant and interesting to the learner" (Donovan et al., 1999). Situated cognition suggests that learning is naturally tied to authentic activity, context and culture (Brown et al., 1989). Situated learning is referred to as learning that takes place in the same context as it is applied (Lave and Wenger, 1991). Moreover, Donald Schön's concept of the reflective practitioner strengthens the relation to contextualised learning and the different situated reflection perspectives (Schön, 1983, 1987) that can be taken.

In order to explore the potentials of mobile and pervasive information technology to support learning it becomes a necessity to take an interdisciplinary perspective. Hence, a combination of technical models and concepts from research on ubiquitous computing, human-computer interaction, and computer-supported ubiquitous learning as well as educational theories and cognitive, respectively, social psychology research is needed.

1.2 Ubiquitous learning characteristics

Since the idea of ubiquitous computing introduced by Weiser (1991) with its subdomains pervasive and mobile computing has first appeared, the relation between people and computing devices and thus the impact of technology on learning has dramatically changed. In this context, education is considered as one of the main application areas for ubiquitous computing (Barbosa et al., 2008), offering mobility combined with pervasive computing functionality (Lyytinen and Yoo, 2002). The enormous possibilities for learning still need to be investigated. On the one hand there is the promise of a seamless integration and enhanced support for learning in action and on the move. On the other hand, the diversity and continuous modification of technologies, changed interaction modalities and usability requirements, the mobility of content, as well as the overwhelming amount of information challenge the learner and demand high standards for corresponding learning environments. Coping with these challenges postulates new approaches of information processing, interaction, and instructional design emerging from the characteristics of ubiquitous learning.

The ubiquitous computing approach establishes a basis for innovative informal and non-formal learning (European Commission, 2001) scenarios that are learner activated, situated as well as activity- and experience-based (Beckett and Hager, 2002) complemented by an increasing contextualisation of content. The embodied mobile learning paradigm encourages learning that is personalised, authentic, and situated (Traxler, 2009a). Based upon this paradigm but differentiated in its level of embeddedness in the environment is ubiquitous learning, which conceptually rests upon the idea of ubiquitous computing. Enhancing learning environments with mobile technologies and pervasive functionality creates ubiquitous learning environments, in which different channels of information and interaction are synchronised and orchestrated by instructional designs.

Permanency, accessibility, immediacy, interactivity, situatedness, and adaptability have been identified as the main characteristics for ubiquitous learning embedded in our daily life (Ogata and Yano, 2004). A closer examination reveals that permanency, accessibility, as well as adaptability deal with informational aspects, whereas immediacy and interactivity relate to aspects of interaction and situatedness describes an instructional design aspect. Covering all the main characteristics of ubiquitous learning, the mentioned aspects are applicable research clusters that can be explored in greater detail.

1.2.1 Information aspects

Nowadays, information is widely distributed as we are creating a constantly growing number of digital content using the means of digital media, such as pictures, videos, bookmarks, or web-log entries. Following the principles of participation, syndication, and tagging (O'Reilly, 2005), the content is distributed all over the web and gets more and more enriched by metadata, enabling a collaborative annotation and classification. Considering the amount of available digital content finding the right information becomes more and more important (Traxler, 2009a). This indicates a need of information navigation competences and postulates the support and assistance of learners in order to enable them to navigate more efficiently through information and find the right information in any given situation (Koole, 2009). One essential aspect to implement this concept is to keep the learner continuously aware about the environment he is active in, including digital content and services that are available in a real world context. Clearly, the challenges are to improve the identification of relevant digital content and services, to simplify the access mechanisms, as well as to enable and facilitate contextual relationships to provide a better support for learning.

Identifying relevant content can be done using the enriched metadata, for example social classifications that offer a promising information retrieval potential (Morrison, 2007). A popular approach to combine content and functionality from two or more external sources is the creation of mash-ups. This core functionality of the Web 2.0 offers a great potential to enrich learning experiences and paves the way for empowering personal learning environments (Wild et al., 2009). Mash-ups ease the access to distributed information and establish new coherences never considered before. This includes linking digital content not only to people, but also to physical and virtual objects, for example by adding a geo-location to a picture. Also, the other way round more and more physical and virtual objects get enriched with content and functionality and thus becoming service interfaces for digital media (Sterling, 2005). Towards an 'internet of things' (Dodson, 2003) these links are already used to integrate physical and virtual objects into existing social networks of people or even create social networks of things, by giving these objects an identity (ThingD, 2010; Thinglink, 2010). These services massively collect things that are linked together not only by people but also by their associated digital content.

Regarding the mentioned information aspects of ubiquitous learning finding appropriate support and assistance strategies for contextualised learning sets up the focus for further research. Therefore, the existing links between people, objects, and data need to be facilitated to identify digital content that is available in a real world context and thus can be contextualised to enrich the situated learning experience.

1.2.2 Interaction aspects

The constant change of interaction modalities is closely connected to the continuous technical development and the related computational models. Starting from the electronic paradigm for interaction with the computer, over to the emergence of symbolic and textual forms as more intuitive forms of interaction, resulting in graphical representations – more and more human abilities were considered in human-computer interaction design. By gradually incorporating more skills and abilities, the resulting interaction principles made computation "more widely accessible to people without requiring extensive training, and to be more easily integrated into our daily lives by reducing the complexity of those interactions" (Dourish, 2001). This process is ongoing and new concepts are emerging, as mobile technologies and pervasive computing change once more the role of computation.

An interaction approach that goes beyond conventional graphical user interfaces for personal computing is the use of ambient media in the periphery of the user. Associated with a more tangible and social interaction corresponding systems make use "of the entire physical environment as an interface to digital information. Instead of various information sources competing against each other for a relatively small amount of real estate on the screen, information is moved off the screen into the physical environment" (Wisneski et al., 1998). Thereby, the used displays in the background are an addition to existing personal interfaces in the foreground, while the user attention can always move from one to the other or vice versa.

From another point of view, this more embodied interaction and the rather situated than individualised design approach triggered by embedding information technology into the physical world extends the digital world beyond the desktop, thus becoming an "ambient social infrastructure" (McCullough, 2004). This aspect goes hand in hand with the call for engaging user experiences, "where technology is designed to enable people to do what they want, need or never even considered before by acting in and upon the environment" (Rogers, 2006). Carrying this idea a bit further even leads to a possible fusion of physical objects with digital information. This notion of blending the real and the digital world is connected to the concept of mixed reality, where physical and digital objects co-exist, interact, and enhance each other. As part of the continuum between real and virtual environments (Milgram et al., 1994) the concept produces new environments and augmentations and can be differentiated in augmented reality (covering all digitally enriched environments) and augmented virtuality (describing virtual environments that are enhanced by physical objects), although clear boundaries between the different parts of the continuum do not exist.

In a world where information is widely distributed and highly contextualised, ambient systems incorporating the mixed reality concept can be used to enable the access to digital content that is available in a real world context, building on the links between people, objects, and data. Facilitating these new interaction approaches for a better ubiquitous learning support extends the research focus.

1.2.3 Instructional design

The changed paradigms of information handling and interaction offer a strong potential to provide both powerful contextual, in situ experiences and discovery of the connected nature of information in the real world. Most notably simple augmented reality (mainly facilitated through mobile technologies) currently attracts a lot of attention and is considered as one of the future trends for learning offering exactly the described potential (Johnson et al., 2010). New technologies are adopted rapidly and digital content becomes more important for learning. Also, the type of tools used for learning is changing towards social software tools and web 2.0 services (Tools for Learning, 2009). The modelling of ubiquitous learning support has been discussed in relation to the use of IMS LD and the orchestration of learning activities. Several challenges for ubiquitous learning support with IMS LD are discussed by Zervas et al. (2011) while Dillenbourg and Jermann (2010) have summarised the current implications from the orchestration perspective. In a next step, the implications for ubiquitous learning need to be investigated.

Following the situated learning approach (Lave and Wenger, 1991) ubiquitous learning is embedded within activity, context, and culture. By definition, this happens in particular social and physical environments that need to support the learning process. Furthermore, social interaction and collaboration are essential components, as learners involved in 'communities of practice' co-construct knowledge as a social process. In authentic situations, the problem and its context are defining each other, while the learning process does not involve the acquisition of abstract knowledge that is out of context. Solving a problematic situation includes the identification of the problem as unresolved issue, the specification of an approach depending on the current situation the learner is in, and finally the determination of solutions or, respectively, the generation of sub-problems that break down the original problem. Thereby "the problems encountered as well as the knowledge required are all presented in their natural and authentic forms" (Ogata and Yano, 2004).

Regarding the instructional aspect of ubiquitous learning, supporting the learning process in the social and physical environment where it is happening and enabling learners to construct knowledge complements the research focus. Thereby, this process can be of a personal, social, or environmental kind.

1.3 Towards ambient learning displays

Although informal learning contexts become increasingly important for lifelong learning, there is still a divide between existing (traditional) learning environments and the real-world context. The current major problem is that ubiquitous learning is not supported in its situatedness, authentic context, and social dependencies. This is due to the insufficient utilisation of the mobile capabilities of the learner and the pervasive functionality of the physical environment in which the learning takes place. Ubiquitous access to learning support fosters new opportunities, such as content filtering by context or contextualised access to interaction facilities. Context in that sense is described as a broad concept, which allows adaptation "according to the location of use, the collection of nearby people, hosts, and accessible devices, as well as to changes to such things over time." (Schilit et al., 1994), but might also include environment-induced aspects, for example illumination, noise, and network connectivity.

Offering a variety of display and interaction modalities that can be utilised by the learner is an actual strength of ubiquitous learning environments. Thus, the learner is almost free in the learning process. This main strength implicitly holds a major problem. Learners are confronted with missing awareness indicators reflecting the available learning support in their current environment including relevant digital content meaningful within the situation, context, or activity the learner is in. The main reason for that is the wide distribution of content among different devices, platforms, and providers. Finding the appropriate content is difficult as it often takes more time and effort than it actually benefits. Once identified, accessing the desired content is also difficult, as the different service interfaces differ in design and implementation as well as the used interaction metaphors differ among the learner's different devices, systems, and platforms. What makes it even more difficult is that digital content is often not linked and accessible in a contextualised manner (e.g., links between digital content and real-world objects). The other way round it mostly is not possible to create these links. Furthermore, the threshold to reach the desired awareness gets insuperable, due to the vast amount of available content, which is constantly growing.

To sum up, the main problem is that ubiquitous learning is not supported in its situatedness and authentic context. One reason is that relevant awareness indicators reflecting the available support are missing. This is due to the wide distribution of content; the difficulties of finding and accessing appropriate content and an insufficient contextualisation of content. The depicted problems lead to derived research questions and objectives outlined in the following sections that need to be answered and accomplished.

1.3.1 Research questions

As common techniques and traditional learning environments do not support ubiquitous learning and the required awareness for relevant resources in a sufficient way, the integral parts of ubiquitous learning support need to be examined to define the research questions and after all solve the delineated problems. More precisely, this involves the acquisition, processing, and delivery of learning support framed in authentic situations. Correlating these parts with the enumerated informational, interactional, and instructional aspects of ubiquitous learning and their discussed development potentialities lead to the following broad research questions:

- Which types of digital content can support learning in ubiquitous learning environments? How can this content be condensed to create meaningful mash-ups?
- Which sensors, displays, and artefacts can be used and how must they be aggregated, filtered, and implemented in ubiquitous learning environments?
- Which methods of interaction and information presentation can be used to create awareness in ubiquitous learning environments?
- How are the awareness methods assimilated and perceived in ubiquitous learning environments and what are the implications for the design?
- Does the utilisation of contextualised digital content support and enhance the learning experience in ubiquitous learning environments and what are the effects?

To formulate the research objective more specific research questions are needed, bringing into focus the distinguished characteristics of authentic learning situations including the personal and environmental sense-making process and the development of problem solving strategies.

- Which information is relevant for learners in authentic learning situations within ubiquitous learning environments and how can this information be

obtained and aggregated?
- How can ambient interaction modalities improve the availability and accessibility of this information within ubiquitous learning environments?
- Is the improved availability and accessibility of relevant information an effective support in authentic learning situations?

Assembling these specific research questions taking into account the general focus on learning as well as the feasibility of their investigation, leads to the research question that the authors eventually set up to answer in further research work: What are the effects of ambient information presentation on learning in a situated learning context within ubiquitous learning environments?

1.3.2 Research objectives

Apparently, the general research objectives emerge from the intercourse with the specific research questions compiled in the previous section. Hence, the objective is to support learners in authentic learning situations within ubiquitous learning environments. They should be empowered to solve problems, generate knowledge interactively, and interact appropriately. Furthermore the learners need to be aware of their position within the community of practice they are in during the learning process as well as their progress in acquiring the constructed knowledge.

The underlying learning process, especially the personal sense-making process and the development of problem solving strategies, needs to be supported where it is happening. Enabling the learner to navigate more efficiently through information and find the right information in any situation is essential. The available information needs to be presented in authentic contexts, settings, and situations that would normally involve the represented knowledge. Furthermore, this information should be moved off the screen into the physical environment making the representation as well as the interaction with it more social, tangible, and physically perceptible. More condensed, the primary objectives of further research work are as follows:

- establish the awareness for information relevant for situated learning within ubiquitous learning environments
- examine the personal, social, and environmental sense-making process facilitated through ambient information presentation within ubiquitous learning environments
- evaluate the situated learning support in authentic learning situations on its effectiveness for learning, especially to solve problems in context.

Designing such a system the authors intend to facilitate mixed-reality information mashups of digital content and use different ambient channels to distribute this information across contexts and devices. Finally their effects on the situated learning process, resulting in ambient systems for learning – or in other words the envisioned ambient learning displays – will be measured. As a secondary objective the research activity outcomes can contribute to a definition of functional requirements for a ubiquitous learning support framework. The framework will give suggestions and provide guidelines for the design and implementation of future ambient systems and applications for learning, easing and aiding the situated learning support.

1.3.3 Provisional conceptual framework

To accomplish the research objective and answer the research question several aspects need to be considered. The information presented in context needs to be acquired, channelled, delivered, and framed in the learning process. In this regard relevant research findings, models, design dimensions, and taxonomies have been examined resulting in a conceptual framework that provisionally defines ambient learning displays (Börner et al., 2010b) and consists of parts dedicated to acquisition, channelling, delivery, and framing (see Figure 1.1).

Within the framework awareness as one of the key concepts for informal learning support (Syvanen et al., 2005) is used as acquisition instrument of the information relevant for the learner within the ubiquitous learning environment (Ogata, 2009). Consequently, the acquired social, task, concept, workspace, knowledge, and context awareness information sets up the conceptual framework. In order to present the acquired information in context the ambient information channels model introduced by Specht (2009) is utilised to carry on the conceptual framework. Within the model ambient channels are used to deliver information and services but also to feed information back into the system. Thereby, information might be channelled into visual, auditory, haptic, odorous and respectively tasting extraditable parts. To deliver the previously channelled information within the ubiquitous learning environment ambient systems are used. Based on the comparison and discussion of existing ambient information systems by Pousman and Stasko (2006), the four design dimensions: information capacity, notification level, representational fidelity, and aesthetic emphasis are used to design ambient systems as means of delivery. The framing of the previously acquired, channelled, and delivered information in a learning context then complements the conceptual framework. Based on the revised taxonomy of educational objectives of Anderson and Krathwohl (2001) activities and objectives enabled by the systems are matched to the types of knowledge and the cognition processes involved. Thereby the taxonomy describes on the one hand several cognitive process dimensions ranging from remembering over applying

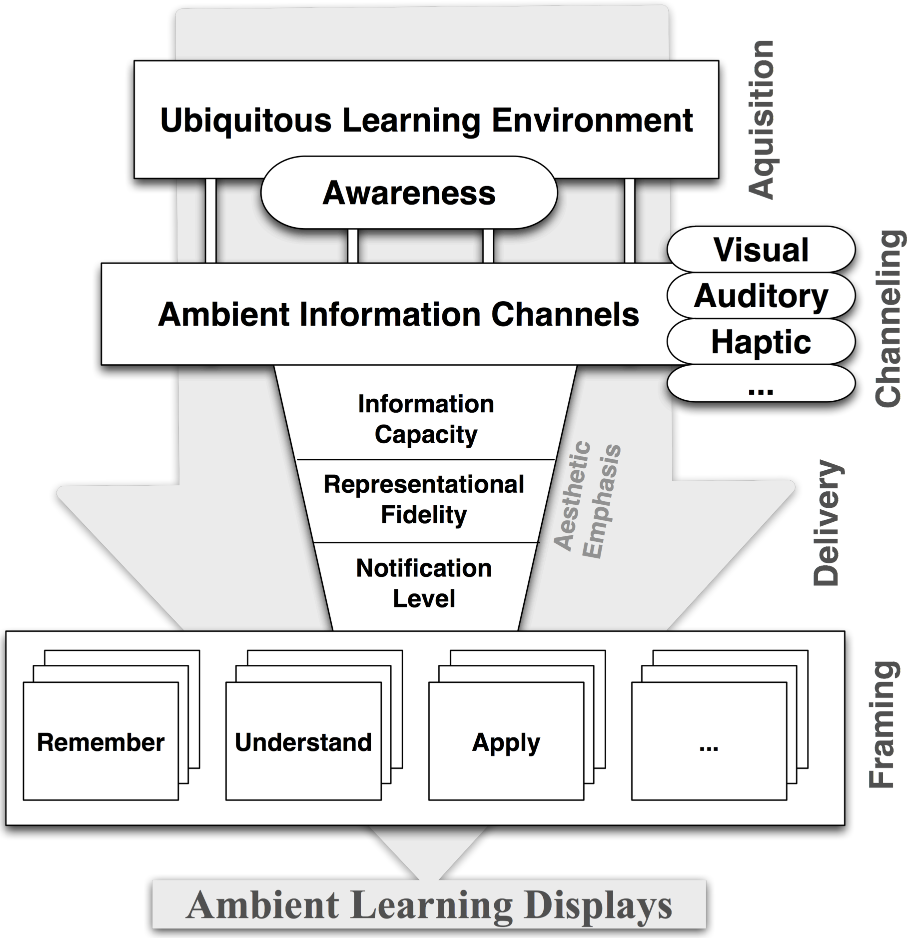

Figure 1.1: Provisional conceptual framework for ambient learning displays

to creating and distinguishes on the other factual, conceptual, procedural, and metacognitive knowledge.

But how would relevant information actually flow through the proposed conceptual framework? Assuming an example setup where the users are asked to identify existing learning objects/resources available in their proximity and match them according to the context they are used in. Thereby context describes the relation of a learning scenario and the location where the scenario takes place. This task addresses a simple cognitive process dimension dealing with factual knowledge. An ambient system fed with information reflecting the awareness needs of the users operating within the environment would be used to support the task. Depending on the activity (derived from the addressed cognitive process dimension) that needs to be supported, this information is channelled through ambient information channels utilising different means and modalities to deliver appropriate input for the ambient systems.

In such a setup creating workspace awareness could mean to use an ambient visualisation method to describe possible learning scenarios. Concerning knowledge awareness ambient audification methods could be used to create awareness when someone enters the environment who created a certain learning object/resource and thus might assist with the matching. And to provide a last example, vibration could be used as a possible ambient haptification method to create context awareness reflecting the spatial proximity of the learning object/resource to its learning scenario, respectively the designated location.

1.4 Research agenda

Heading towards the implementation and manifestation of the envisioned ambient learning displays an agenda for further research work has been set up incorporating the outlined research questions and objectives. Based on this agenda the authors propose a research project described in the following sections depicting an experimental design as well as a usable evaluation technique.

In preparation of the research project a small-scale study (Börner et al., 2010a)[1] has already been conducted to gather opinion of experts in the field of mobile and ubiquitous learning on the educational problem that can be solved by mobile learning. For this purpose Concept Mapping (Trochim, 1989b) has been chosen as an appropriate method. The method provides a structured approach to identify the experts' opinion on a given domain, including both qualitative techniques and multivariate analysis approaches. The result is a visual map of useful and important concepts that can then be used for further elaborations. The study revealed that the two most important problem clusters are dealing with 'access to learning' and 'contextual learning' aspects. Focusing on these problem clusters and the covered problem descriptions in detail gives valuable insights on the educational characteristics that define mobile and ubiquitous learning. For the presented research agenda, these results of the study are used both as indicators for the educational focus and as an instrument to validate the research findings.

The actual research design will begin with an extensive literature review covering in general the aspects discussed in Section 1.2 with a clear focus on ambient systems. Regarding ambient systems there is a particular interest in existing applications used to support personal, social, and environmental sense-making processes; derived

[1] This publication is included as **Chapter 4** in this thesis.

patterns for the design of such applications; and criteria and techniques that have been used for evaluation. It is expected to find a large number of ambient systems that simply represent information rather than supporting more complex cognitive processes. In any case, it needs to be investigated if and how the applications are used within learning scenarios and how they are evaluated on their effectiveness for learning.

Towards a profound conceptual framework that finally establishes the basis to build prototypes for an experimental design, a lot of work has already been done as described in Section 1.3.3. Under the assumption that the information presented in context needs to be acquired, channelled, delivered, and framed in the learning process, relevant research findings, models, design dimensions, and taxonomies have been examined. Though the outlined provisional conceptual framework for ambient learning systems is still subject of modifications. Most probably the modifications will be due to the gathered insights from the literature review of existing ambient systems for learning as well as the evaluation techniques for respective applications.

1.4.1 Experimental design

Based on the prior literature review and the resulting conceptual framework analysis an experimental design will be used to evaluate the prototypes built upon the conceptual framework. Prior to the design it is planned to conduct formative studies to gather insights on the specific usability needs and requirements of ambient systems and aid the design process. Then a setup of ambient system prototypes, addressing specific cognitive process dimensions, varied on the values of single design dimensions will be designed and implemented. There is a particular interest in the effects on learning affected by the way the ambient systems present information. The goal is to unveil in summative studies how the single prototypes and prototype setups perform. The experimental design is oriented on design-based research (Baumgartner et al., 2003), following a recurrent cycle of designing an experiment, implementing the experiment, and evaluating the results in order to review the experimental design again.

An example setup for such an experiment can be illustrated as follows: the ambient system is fed with information reflecting the awareness needs of users operating within the ubiquitous learning environment. Depending on the activity (derived from the addressed cognitive process dimension) that needs to be supported, this information is channelled through ambient information channels to deliver appropriate input for the ambient systems. Each ambient design dimension can be varied on its distinguished values. In this first experimental cycle the effect when manipulating these values on each dimension will be measured, to figure out if and how this influences the performance of the given activity and thus is effective for learning or not.

A possible hypothesis in such an experiment would be that ambient systems with a low information capacity, an abstract representational fidelity, and a level of notification that only makes aware, benefit the cognitive process dimension 'remember'. To test this hypothesis, the single ambient design dimensions would then be varied and compared to each other. To do so, quantitative and qualitative data using data logs, questionnaires, as well as a specific evaluation technique described in the next section will be collected.

1.4.2 Evaluation technique

To investigate and determine if the envisioned experimental prototypes are suitable to support learners in authentic learning situations within ubiquitous learning environments an appropriate evaluation technique is needed. Due to the nature of ubiquitous learning finding suitable techniques is rather difficult. Users constantly move across contexts, change environments, and usually are not restricted to act within a closed testbed for evaluation. Thus, the experienced conditions cannot be controlled completely nor kept similar. Therefore traditional evaluation techniques, such as pre-test/post-test designs, are not sufficient. Instead the evaluation has to be done also in situ, taking into account the current context, environment, and conditions the user is experiencing. The challenge though is to find an appropriate technique that allows measuring the effects in authentic learning situations. For ambient systems as well as ubiquitous learning applications corresponding methods will be explored during the literature review. One method that is already in the focus of attention is the experience sampling method. The method has already been applied and examined for ubiquitous computing applications. Derived from the field of psychology the technique is especially effective for learning about situations and person-situation interactions and allows to "take place in situ, involve several participants, take place over time, and collect both qualitative and quantitative data" (Consolvo and Walker, 2003). The technique uses several brief adoptable questionnaires to let the participants report about their current activity and the situation they are in. The participants are alerted in situ and asked to respond by filling out a brief questionnaire. Traditionally used to evaluate aspects like emotion, performance, or social interaction, the technique seems also sufficient to evaluate ambient systems for learning.

Coming back to the example given in the previous section the method could be applied as follows. Each participant is assigned to a specific task, which is to identify and match existing objects/resources. To complete the task, the participants need to perform certain actions. In the moment they completed the assigned task an event is triggered that delivers an adapted questionnaire taking into account the current situation and context the participant is in. The participants are then asked to indicate, for example which information supported them to solve the task or which ambient system supported them to solve the task. Using statistical methods on the surveyed qualitative and quantitative data finally allows measuring the effectiveness of the ambient information presentation for learning through the performance of the participants.

1.4.3 Discussion

While elaborating the research project some issues and challenges mainly related to the undetermined target domain used to conduct the experiments, the evaluation of ubiquitous scenarios in laboratory settings, as well as the importance of aesthetic design for the experiments emerged. The issues related to the application domain are rather complex. Quite reasonably the chosen application domain has a great influence on the learning conditions. Authentic and situated learning usually occurs when learners are strongly related to the placement they are active in and at the same time far away from traditional (mostly formal) learning capabilities they would usually make use of. The characteristics of the current placement and the requirements of the learners have in fact a great influence on the assumptions the learners may have, the conditions they may find in situ, as well as technical constrains of the settings. The chosen domain has an impact on the conceptual framework and hence on the experimental design and the evaluation and thus has to be chosen carefully.

The evaluation of ubiquitous scenarios in laboratory settings is self-contradictory. While ubiquitous computing and the derived ubiquitous learning scenarios are characterised by the "anywhere, anytime" paradigm, laboratory settings per se exclude these features as they postulate the full control of all confounding variables. Evaluation techniques need to take into account the current context, environment, and conditions the user is experiencing within the situation that is observed. One possible solution has already been mentioned in Section 1.4.2 describing a method already used to evaluate ubiquitous computing applications (Consolvo and Walker, 2003). Still, other available methods need to be investigated and verified on their adequacy for the evaluation of ubiquitous learning applications and thus ambient systems for learning.

Another issue is the importance and influence of an aesthetic design especially when heading for an end-user product. The aesthetic emphasis is one of the dimensions affecting the design of ambient systems (Pousman and Stasko, 2006). Within the presented research project, this dimension will be mostly ignored. The reason for that is mainly the focus on evaluating the effects of ambient information presentation on learning and learning support rather than actually designing end-user products. In this context emphasising the aesthetics design dimension of ambient systems too much is simply not feasible for the research project, but definitely needs to be considered when applying the outcomes to actual learning scenarios.

1.5 Conclusions

The chapter outlines the authors' vision of ambient learning displays – enabling learners to view, access, and interact with contextualised digital content presented in an ambient way. The vision is based on a detailed exploration of the characteristics of ubiquitous learning and a deduction of informational, interactional, and instructional aspects to focus on. Towards the vision essential research questions and objectives as well as a conceptual framework that acquires, channels, and delivers the information framed in the learning process are presented. Furthermore, a research agenda proposing a research project is presented. This research project offers rich opportunities for the design of environments following the mobile and ubiquitous learning paradigm, which gain in importance for technology enhanced learning (TEL). Recently, the EU-funded project STELLAR identified the grand research challenges for the future of TEL. As a guideline, three themes have been formulated: connecting learners, orchestrating learning, as well as contextualising virtual learning environments and instrumentalising learning contexts (STELLAR, 2009). The authors' vision of ambient learning displays is strongly devoted to the contextualisation theme; implicating manifold overlaps with the other themes. Therefore the main research outcomes will also flow back into the contextualisation theme. The main idea behind the theme is to encourage situated learning, while supporting the learner's mobility. Building on that, the key research questions in this theme are:

- How can new forms of contextualised learning enable novel experiences for learners and for development of human competences?
- How to support the mobility of the learner in distributed and multi environment learning settings, like the transition between real and virtual contexts?
- Which standards are needed to achieve interoperability and reusability of learning resources in this field? How to harmonise the existing learning standards?

Comparing these key research questions with the presented vision, clarifies the relevance within the field. The authors' vision of ambient learning displays highlights the challenges and explores the possibilities that lie in the convergence of mobile and ubiquitous learning in combination with the utilisation of contextualised digital content as valuable resources to support learning.

Furthermore, the outlined research project delivers new scientific insights into the authentic learning support in informal and non-formal learning situations. Within ubiquitous learning environments the project will investigate if there is a measurable benefit utilising ambient information presentation for a contextualised learning support. From a practical point of view this research will flow into a framework that gives guidelines for the future design of ambient systems for learning.

Part II

Formative Studies

Chapter 2

Expert concept mapping study on mobile learning

To inform the theoretical work as well as the design and development of ambient learning displays from different perspectives, several formative studies were conducted. This chapter describes an explorative study based on a concept mapping approach involving international experts from the field of mobile learning. These experts were asked to identify the major educational problems that can be addressed by mobile learning and cluster these problems into domain concepts that contribute to a definition of mobile learning. Although the study targeted on mobile learning, the results are in a broader view also valuable for the ubiquitous learning domain and thus for the research on ambient learning displays as they make use of key concepts, such as contextualisation and adaptation of information presentation to the user context and other situated factors.

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2.1 Introduction

So far there have been lots of attempts to define mobile learning, such as "learning that happens when the learner takes advantage of learning opportunities offered by mobile technologies" (O'Malley et al., 2003). The perspectives taken are either technocentric (like in the given example), consider the mobility of the learners, or rest upon the anytime/anywhere paradigm of existing content (Winters, 2006; Taylor, 2006). Each of these different perspectives is extensively discussed in the literature (Sharples, 2006; Traxler, 2009b), but by now there is no generally accepted definition, nor an agreement on which perspective to consider finding one. Especially the technocentric perspective is highly controversial as the underlying development of mobile technologies is continuously progressing, making the attempted definitions highly unstable (Traxler, 2009b).

A more promising way towards a theory of mobile learning (Sharples et al., 2005) seems to be the focus on the clarification of significant issues (Sharples, 2006), research challenges (Arnedillo-Sánchez et al., 2007), case studies (Kukulska-Hulme and Traxler, 2007; Traxler, 2009b), or motivational or affective aspects (Jones et al., 2006). All these attempts contribute to a definition of key characteristics for mobile learning and sharpen the picture of what constitutes mobile learning rather then finding a precise definition. Traxler (2009b) even suggests replacing the question 'what is mobile learning?' by the questions 'what is learning in a mobile age?' or 'what is mobile *learning*?' focusing more on the educational part of the domain. Following this suggestion we decided to conduct an explorative case study (Krathwohl, 1993; Yin, 1994) within the mobile learning domain that is not taking one of the perspectives mentioned earlier. Instead, the focus was set on the educational problems that underpin the expectations on mobile learning, while at the same time trying to find an adequate conceptualisation of these problems. Therefore the following research questions have been defined:

1. What are the educational problems that mobile learning is trying to solve?
2. Which problem clusters can be identified and how are they emphasised?
3. How are the different problem areas related within the overall research domain of mobile learning?

In the following sections we will introduce the applied method, analyse and evaluate the results, and finally discuss the findings and their relevance for the domain of mobile learning.

2.2 Method

To answer the formulated research questions, the presented study implements the concept mapping approach that has been initially described by Trochim (1989b,a). This method has already been applied in several studies (Stoyanov and Kirchner, 2004; Wopereis and Kirschner, 2005). It provides a structured participative conceptualisation approach to identify clusters of ideas and opinions generated by experts for a given domain aspect. The collected data is then analysed via multidimensional scaling (Kruskal and Wish, 1978; Davison, 1983) and hierarchical cluster analysis (Anderberg, 1973; Everitt, 1980). The result is a set of visual maps representing the generated idea and opinion statements as well as emerging statement clusters and thus important domain concepts. The method consists of several phases to prepare the collection of data and finally collect the data, each of which is described in the following sections.

2.2.1 Preparation

The initial phase of the method has three objectives: defining an initial focus or trigger statement for stimulating the generation of ideas and opinions, selecting key dimensions for rating the generated statements, and selecting the participants.

Derived from the first research question the following trigger statement has been chosen: "The educational problem that mobile learning tries to solve is...". Based on the experiences of previous studies (Stoyanov and Kirchner, 2004; Wopereis and Kirschner, 2005), "importance" and "feasibility" were selected as respective key dimensions. These qualitative dimensions emphasise different aspects of the practices within the domain. The importance dimension refers to the relevance of an educational problem within the mobile learning context. The feasibility dimension refers to the potential of mobile learning for contributing to a sufficient solution for the related educational problem.

Finally the participants were selected from the member list of the International Association for Mobile Learning (IAMLearn, 2009). In total 32 international acknowledged domain experts have been invited to participate in the study. The invitees represented different stakeholder groups within the mobile learning domain, ranging from industry via research to educational practitioners. 20 out of the 32 invited experts accepted the invitation to participate in the study. Given to the international distribution of the participants, the communication as well as the data collection has been conducted entirely online via e-mail messages.

2.2.2 Procedure

The procedure to collect the data consisted of two phases: generation of idea and opinion statements and structuring the generated statements. Due to the characteristics of the method, the participants were actively involved in both phases of the data collection process. The phases are described in greater detail in the following sections.

Generation of Statements

In the first phase of data collection the participants were asked via e-mail to generate ideas and opinions on the previously defined trigger statement. The participants were instructed to simply reply to the e-mail message and include their identified educational problems as short bullet point statements underneath the trigger statement. The participants were free to generate as many statements as they wanted to. Although no direct control could be imposed on this process the participants were requested to describe exactly one educational problem in each statement and if possible limit the generation process to 10 minutes.

During this first phase, 11 experts generated 70 statements elaborating on the given focus in form of the trigger statement. Sighting the list of generated statements revealed an issue that needed to be solved before going on with the next phase. Almost each participant used an own structure to describe the ideas and opinions, which complicated the comparison of the statements. Therefore the statements were restructured into grammatically correct sentences and simultaneously revised for spelling mistakes. In doing so another issue was revealed, as some statements described more than one specific idea. To resolve the issue the relevant statements were taken apart and again restructured into grammatically correct sentences. Finally all the statements were compared to eliminate obvious duplicates, resulting in a list of 82 unique statements (e.g. "Maintaining continuity of learning across settings, such as between classrooms and museums on school field trips.") that could be used for the next phase.

Structuring of Statements

In the second phase all participants were asked to structure the statements that were collected during the first phase. The participants were contacted no matter weather they generated statements in the first phase or not. The structuring of the statements involved two independent steps: grouping the statements based on their perceived similarity in meaning and the rating of the statements. In order to collect as much information as possible from the participants while reducing the communication overhead, the two steps were combined using a single e-mail message. To ease the process for the participants three documents were attached to each message. One provided the complete list of all unique statements. The other two documents were used to record the results of the grouping and rating. The participants were asked to perform the structuring of the statements within two weeks. 9 experts participated in the structuring phase, grouping and rating the statements that were previously generated.

Step A: Grouping

In the first step the participants were asked to group the statements based on their similarity in meaning. The participants were asked to copy the statements from one document containing all statements into a second document containing a prepared form with empty group containers. The participants were informed that they should place all statements into one group only, while each group should contain statements that were similar in meaning to each other. The instructions emphasised that the similarity must focus on the content of the statement and not on importance or feasibility of the statement. If a statement in the participants' opinion was unrelated to the other statements or stood alone as a unique idea, they were allowed to put this statement in its own group. In any case they were neither allowed to create arbitrary groups such as "misc" or "junk" groups. Again the experts were free to create as many groups as they liked, suggesting that in most cases using 10 to 20 groups should work out well. When finished the participants were asked to create a label for each group that described the included statements. In total, the experts created 111 groups with an average of 12 groups per expert.

Step B: Rating

After grouping the statements the experts were asked to rate all statements in a third document. Each statement had to be rated on the key dimensions "importance" and "feasibility" on a 5-point Likert-scale. For importance the quantitative value 1 meant the statement described a less important educational problem that mobile learning is trying to solve and 5 meant the statement described a highly important educational problem. Respectively, for feasibility the quantitative value 1 meant solving the described educational problem through mobile learning is not feasible and 5 meant it is feasible to solve the problem through mobile learning.

2.3 Results

2.3.1 Data Analysis

To analyse the collected data the concept mapping approach proposes statistical data analysis techniques to map and then cluster the problem statements. Additionally the average ratings for each problem statement and the respective problem clusters are calculated and can be incorporated in the resulting visualisations for further interpretation. In the presented study all required calculations and visualisations for the analyses were accomplished using the spreadsheet application Microsoft® Excel® version 12.2.4 (Microsoft Corporation, 2007) and the open source software environment for statistical computing R version 2.11.0 (R Development Core Team, 2010).

The concept mapping approach facilitates a non-metric multidimensional scaling analysis (Trochim, 1989b) to map the relation between the statements. In the present study, the statements were mapped onto a two-dimensional space, although multidimensional scaling can be applied across multiple dimensions. Trochim suggests the use of two dimensions, as the resulting bivariate distribution of points on the map is easier to visualise and interpret. Hence, the basis of the multidimensional scaling is a two-dimensional symmetric matrix of similarities of all problem statements. This matrix includes the correlations between the statements based on the expert grouping of the statements. For any two statements 1 is added to the respective intersection point within the matrix, whenever an expert placed the two statements in the same group. The result of the multidimensional scaling is a point map representing the Euclidian distance between the statements based on their similarity. Each point on the map represents a problem statement.

In order to group the statements on the map into clusters of statements, representing important domain concepts, the resulting point map is then used as input for a hierarchical clustering analysis, based on Ward's algorithm for cluster analysis (Trochim, 1989b). This technique isolates the conceptual relationships across statements as they are positioned on the point map obtained from the multidimensional scaling. The difficulty here is to identify a reasonable number of clusters. The concept mapping approach leaves this task open to the judgment and interpretation of the analyst.

Consequently for the presented study the optimal number of clusters was determined through minimising the cluster-size difference of the largest and the smallest cluster and maximising the size of the smallest cluster. After identifying the clusters they were manually labeled. The labels were derived from a list of group labels linked with the cluster and the statements within the cluster. Ideally the group labels provided by the experts converged towards a common domain concept represented by the cluster. If this was not the case, a keyword analysis at statement level was used to find a suitable label. The result of the hierarchical cluster analysis is a cluster map representing the emerging statement clusters and thus important domain concepts. In addition to the points of each problem statement, the map includes the convex hull of the problem clusters. This allows the analysis and interpretation of the relations between the single clusters as well as the associated statements.

2.3.2 Problem Cluster Analysis

As stated, the data analysis techniques were used to map the problem statements, identify, and label the problem clusters. The clusters represent the overarching domain concepts related to the educational problems addressed by mobile learning. Figure 2.1 shows the problem cluster map of the presented study.

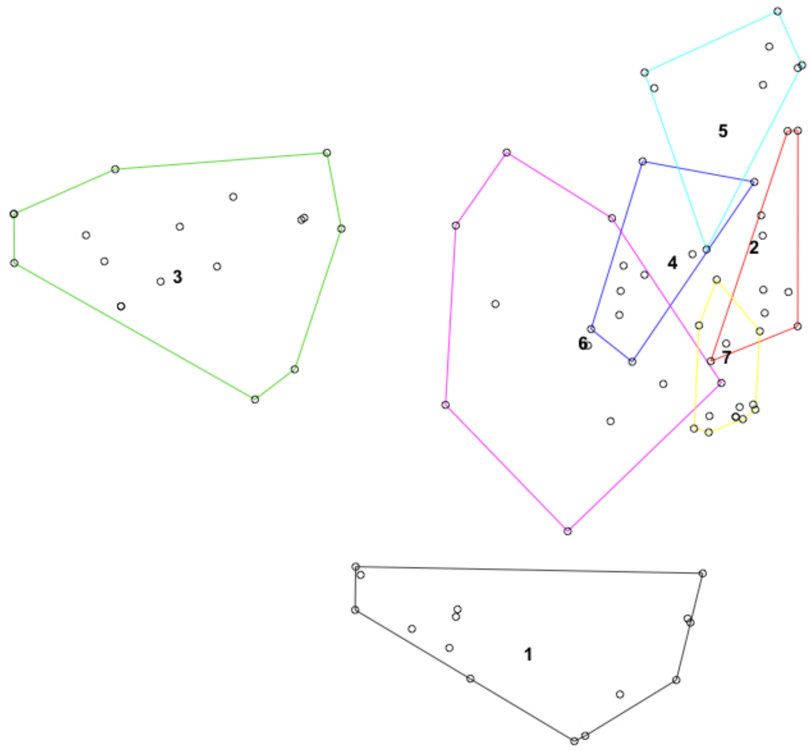

Figure 2.1: Problem cluster map

The complete result data set including all problem clusters and statements can be found in Table 2.1. The following 7 problem clusters covering 82 problem statements were identified:

(1) Access to learning: The cluster covers 15 statements that are mainly related to the challenges of enabling learning in a mobile society. This includes educational problems that are related to flexible learning, including just-in-time learning, equal access to education and learning, and location-based learning. The cluster also covers remote learning and accessibility aspects.
(2) Limitations for learning: 9 statements are included in the cluster. The statements cover challenges related to organisational and educational problems of educational institutions that result from different perceptions of the knowledge society in general and mobile technologies specifically among educators and learners. This also includes the problems of using of mobile technologies in formal learning scenarios.
(3) Contextual learning: The cluster includes 18 statements that highlight the relation between learning and the context in which the learning takes place. The cluster covers individual aspects of situated learning, learning in context, and learning across contexts. Furthermore environmental aspects are included, such as making use of environmental affordances and a stronger interaction with the environment where the learning takes place.
(4) Collaboration: 5 statements are included in the cluster. The statements cover challenges that are related to collaboration, sharing learning resources, and problems related to social interaction, such as difficulties of building a community during learning.
(5) Personalisation: The cluster includes 8 statements. The statements range from educational problems with self-directed learning to mass-customisation of learning and reflect the potential of mobile learning to support personal learning processes and engage learners.
(6) Orchestrating learning across contexts: 14 statements are included in the cluster, which deals with problems related to current educational practices. The cluster is strongly related to the contextual learning cluster, but focuses more on the organisational aspects that mobile learning can support.
(7) Technology and technology adoption: The cluster covers 13 statements addressing challenges related to the technological characteristics of mobile devices and factors of their adoption, including cost-effectiveness, usability, and user-acceptance.

(continued)

Problem cluster *Mean*
Statement *Importance* *Feasibility*

Table 2.1: Rating of problem clusters and statements

Problem cluster *Statement*	*Mean* *Importance*	 *Feasibility*
1. Access to learning	4.03	3.59
17. Access to learning resources and learning opportunities without the restrictions of location, time and cumbersome equipment or facilities	4.44	4.00
59. Access to information when and where it is required, through "just-in time" browsing of relevant information, and information push to support learning in context	4.44	3.89
41. Easing access to educational opportunities	4.56	3.67
25. Mobility of the learner	4.00	4.11
79. Including learners from rural areas	4.22	3.89
61. Accessibility of information in relevant everyday life and work situations	4.33	3.67
9. Learning at anytime	3.89	4.00
80. Developing third world countries' education	4.11	3.78
8. Learning from any location	3.89	3.78
11. Just-in-time information for immediate application	4.11	3.56
1. Limited access by some learners in remote locations	3.67	3.89
51. Enable learners in classroom settings to have equal access to rich resources and computational tools to support curriculum learning	3.89	3.22
78. Including learners with disabilities	4.33	2.78
4. Nomads who move from one location to the next while learning	3.22	3.22
45. Inequality of access to computers, learning resources and teachers	3.33	2.44
3. Contextual learning	3.92	3.60
53. Connect learning across contexts, including between formal and informal settings	4.44	3.78
16. Ability to discover and experiment in own context	4.44	3.67
30. The provision of access to knowledge in the context in which it is applied	4.56	3.56
33. Taking education out of classroom settings into meaningful settings	4.00	3.89
39. Interacting with your environment to achieve new knowledge from it	4.22	3.67
50. Under-utilisation of potentially rich learning resources in heritage sites, art collections and all sorts of other interesting places	3.56	4.22
73. Learning in context	4.00	3.78

(continued)

Problem cluster *Statement*	*Mean* *Importance*	*Feasibility*
74. Learning across contexts	4.22	3.56
58. Using technology to probe or to enrich understanding of the natural environment, and annotating the environment for the benefit of visitors	3.67	4.11
29. The design of augmented contexts for development problem to enable collaborative problem solving where learners generate their own "temporal context for development"	3.89	3.78
12. Learners cannot learn in context	3.88	3.63
57. Making use of affordances of locations to support learning	3.88	3.63
55. Enable enquiry-based learning in novel locations, through novel locations, and about novel locations	3.89	3.44
63. Contextualisation of e-learning	3.67	3.56
56. Making use of space and environment as a backdrop for engaged spatial learning	3.67	3.22
70. The worthwhileness of location-based and contextual mobile learning	3.56	3.33
60. Enable learning through distributed conversation across contexts	3.78	2.78
3. Insufficient real life experience in the learning process	3.22	3.22
6. Orchestrating learning across contexts	3.59	3.28
20. Actively participate in learning activities outside of formal educational settings and facilities	4.44	4.11
24. Flexibility for the learner	4.00	3.89
54. Maintaining continuity of learning across settings, such as between classrooms and museums on school field trips	4.11	3.67
62. Documenting real time experiences of learners	3.89	3.78
37. Design suitable activities for the mobile learners	3.89	3.67
52. Orchestrate new forms of classroom pedagogy that require coordination of individual, small group and whole class activity	4.00	3.33
18. Provision of opportunities to contribute to the development/production of learning resources and course content without the restrictions of location, time and cumbersome equipment or facilities	4.00	2.89
47. Blinkered, old-fashioned views about education stopping when working lives begin	3.44	3.22
40. Anything is a potential learning scenario	2.88	3.50
28. Outside in, inside out problem, where cultural practices involving new digital media can be brought into formal learning institution, get enhanced inside the institution and in turn feedback into the digital world at large	3.22	3.00

(continued)

Problem cluster *Statement*	*Mean* *Importance*	*Feasibility*
46. Pressured, busy, fragmented, mobile lives leaving little quality time for conventional, place-and-time-dependent education	3.33	2.89
64. Transfer of training	3.44	2.56
49. Gaps (time lags) between traditionally scheduled learning sessions, limiting achievement, teamwork and collaboration	3.11	2.56
31. Refreshing the image and practice of institutional e-learning	2.56	2.89
5. Personalisation	3.46	3.13
81. Engagement of the learner	4.44	3.56
15. Not enough self-directed learning activities while learning	3.67	3.78
75. Self-directed learning	3.89	3.11
23. Finding new learning strategies that are suitable for the challenges of, and embraces the opportunities of, the knowledge and information age	3.33	3.11
43. Students exhibit passivity, boredom, indifference, low attention spans, and fail to complete their studies	3.44	2.78
42. The perception that there is a lack of student engagement	3.11	2.89
76. Learning with narratives	2.89	3.11
77. Mass-customised learning	2.89	2.67
4. Collaboration	3.31	3.24
19. Provision of opportunities to collaborate, share and publish learning resources and course content without the restrictions of location, time and cumbersome equipment or facilities	4.33	3.33
65. Spontaneous collaboration in situated learning	3.67	3.33
5. Lack of community building during learning	3.11	3.33
7. Not enough collaboration between learners	2.89	3.44
10. Learners not able to interact with experts from around the world	2.56	2.78
7. Technology and technology adoption	3.32	3.05
36. Make use of the affordable technologies that students have access to	3.78	3.78
66. Harness the fact that every student in every university owns a sophisticated communications device	3.89	3.67
21. Enhance teaching and learning within formal educational settings and facilities through handheld technologies	3.78	3.44
72. Get students to use their mobile devices constantly also in education	3.67	3.56

(continued)

Problem cluster *Statement*	*Mean* *Importance*	 *Feasibility*
34. Helping educational institutions to offer learning aligned to the students' ownership, experience and use of technology	3.89	2.89
69. Dealing with small screens and difficult data input	3.22	3.33
32. Helping educational institutions understand the increasing and near universal ownership, acceptance and use of mobile devices across society	3.22	3.11
27. Cost-effectiveness for the providers of teaching and learning	3.33	2.89
26. Cost-effectiveness for the learner	3.33	2.78
71. Difficulties to reuse the products	3.11	2.56
38. Assess learning experiences to be accountable for the stakeholders	2.78	2.67
67. Revolutionise mobile learning, as the iPhone has revolutionised mobile telephony	2.75	2.38
68. Make mobile learning a revenue stream for telecommunication companies	2.44	2.56
2. Limitations for learning	3.23	2.80
22. Finding new teaching methodologies that are suitable for the challenges of, and embraces the opportunities of, the knowledge and information age	3.44	3.22
2. Lack of support to young learners, which have the mobile technology	3.11	3.44
14. Lack of ICT skills for the twenty-first century	3.33	3.22
82. Transformation of traditional education according to the needs of information society	3.44	2.67
48. Traditionally ineffective instruction and low learner performance in some subjects	3.44	2.56
6. Low motivation of learners who are mobile technology literate	3.11	2.78
13. Teachers not comfortable using mobile technology	3.33	2.56
44. Rigid assessment systems stifle creativity and innovation	3.44	2.33
35. Perceptions of technologically impoverished provision	2.43	2.43

2.3.3 Problem Emphasis Analysis

A detailed analysis of the average rating of the problem statements indicates the experts' opinion about which statements refer to important and feasible educational problems related to mobile learning. Furthermore this analysis also allows estimating the importance and feasibility of the 7 problem clusters as domain concepts. The complete result data set including all problem clusters and statements with attached means can be found in Table 2.1.

Starting with the problem statement emphasis, a statement was considered as important or feasible if the mean was at least 3.5 based on the 5 point Likert-scale rating. An average rating of 3.5 indicates that the experts rated the statement mostly as important or feasible. By taking both rating key dimensions into account the statements can be mapped into four quadrants. Figure 2.2 shows the quadrants and the mapped statements without identifying the actual statements.

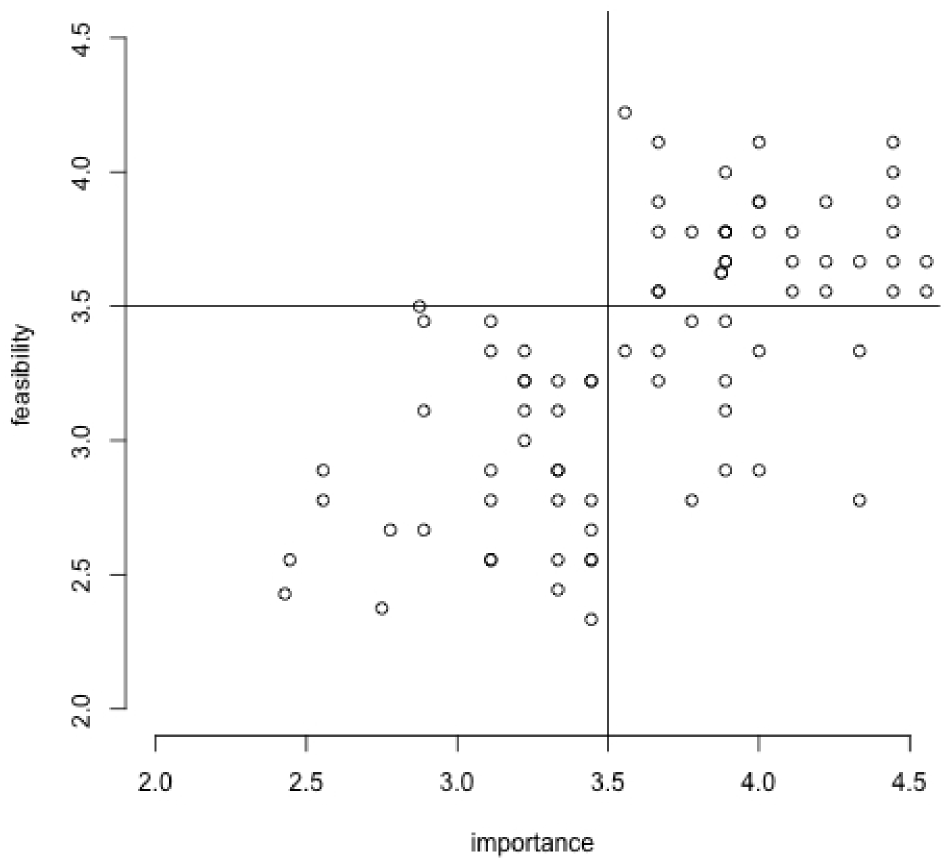

Figure 2.2: Statement rating map

The first quadrant contains those statements that are relevant on both dimensions, with a high average rating on importance and feasibility. Thus included statements refer to the most relevant educational problems addressed by mobile learning. In the experts' opinion 34 statements are located in this quadrant. The majority of the statements are related to the clusters "contextual learning" (13 statements), "access to learning" (11statements), and "orchestrating learning across contexts" (5 statements). The highest rated statements within these clusters are also included in the quadrant. The remaining statements are related to the clusters "technology and technology adoption" (3 statements) and "personalisation" (2 statements). The second quadrant contains statements with a high average rating on importance but low average rating on feasibility. The 13 statements in this quadrant can be considered to refer to important educational problems addressed by mobile learning, while sufficient solutions might go beyond the scope of mobile learning. The statements in this cluster are related to the clusters "contextual learning" (4 statements), "access to learning" (2 statements), "collaboration" (2 statements), "orchestrating learning across contexts" (2 statements), and "technology and technology adoption" (2 statements). The remaining statement is related to the "personalisation" cluster.

The third quadrant contains statements with low average ratings on both dimensions. 34 statements fall in this quadrant. These statements are considered to refer to educational problems that are not specifically related to mobile learning in the experts' opinion. The majority of statements in this quadrant are related to the clusters "limitations for learning" (9 statements) and "technology and technology adoption" (8 statements). The remaining statements are related to the clusters "orchestrating learning across contexts" (6 statements), "personalisation" (5 statements), "collaboration" (3 statements), "access to learning" (2 statements), and "contextual learning" (1 statement). The fourth quadrant contains statements with a high average rating on feasibility but low average rating on importance. The quadrant contains only a single statement that refers to a side educational problem to which mobile learning can offer solutions. This statement is related to the "orchestrating learning across contexts" cluster.

Concerning the importance and feasibility of the problem clusters, the average ratings of all problem statements included in a cluster needed to be considered. This analysis revealed that "access to learning" is rated as the most important cluster in the experts' opinion, followed by the clusters dealing with "contextual learning", "orchestrating learning across contexts", "personalisation", "collaboration", "technology and technology adoption", and finally "limitations for learning". Thus in the experts' opinion the accessibility and contextualisation of learning and education are the most important domain concepts that mobile learning can facilitate. The respective clusters also contain the majority of problem statements and as stated the highest rated statements, listed in Table 2.2. Regarding the rated feasibility the emphasis is similar. The clusters of "contextual learning" and "access

Table 2.2: Highest emphasised problem statements

Problem statement	*Mean* *Importance*	*Feasibility*
20. Actively participate in learning activities outside of formal educational settings and facilities.	4,44	4,11
17. Access to learning resources and learning opportunities without the restrictions of location, time and cumbersome equipment or facilities.	4,44	4,00
59. Access to information when and where it is required, through 'just in time' browsing of relevant information, and information push to support learning in context.	4,44	3,89
41. Easing access to educational opportunities.	4,56	3,67
53. Connect learning across contexts, including between formal and informal settings.	4,44	3,78
16. Ability to discover and experiment in own context.	4,44	3,67
25. Mobility of the learner.	4,00	4,11
30. The provision of access to knowledge in the context in which it is applied.	4,56	3,56
79. Including learners from rural areas.	4,22	3,89
61. Accessibility of information in relevant everyday life and work situations.	4,33	3,67

to learning" are rated as the most feasible domain concepts that mobile learning can facilitate, followed by the clusters dealing with "orchestrating learning across contexts", "collaboration", "personalisation", "technology and technology adoption", and finally "limitations for learning".

2.4 Discussion

Based on the experts' emphasis the used concept mapping approach identified the most important educational problems that can be addressed by mobile learning. The identified problems are all related to the three main domain concepts "access to learning", "contextual learning", and "orchestrating learning across contexts", while most of them are related to the concept "access to learning". This clearly reflects the claim on mobile learning to enable learning across context, facilitating and exploiting the mobility of the learners. The most emphasised issues mainly discuss learning activities and opportunities outside of formal settings, better contextualised and situated learning support, stronger connection between informal and formal settings, and the inclusion of rural and remote learners. Among others these issues indicate the most important current and future use cases for the implementation of mobile learning scenarios. On the other hand the experts considered issues related to technologies and their adoption and usage by teachers, learners and other stakeholders as less important to be addressed by mobile learning. The respective problems are mostly related to the domain concepts “technology and technology adoption” and “limitations for learning”. The emphasis given by the experts does also provide valuable recommendations. Educational institutes and organisations can draw direct conclusions about the core themes of future research agendas and implementation plans out of the study results. To provide an example, the most relevant problem statement within the “Contextual learning” cluster is “Connect learning across contexts, including between formal and informal settings.” The statement is positioned in the first quadrant of the statement rating map shown in Figure 2.2, as it got a high average rating on importance and feasibility. In the experts’ opinion facilitating learning across contexts is one of the most important challenges in the domain of mobile learning. At the same time there seem to be sufficient solutions to cope with that challenge. The conclusion that can be drawn is that these solution need to be implemented on a short term.

Contrary to this example is the problem statement “Enable learning through distributed conversation across contexts.” covered in the same cluster. The statement is positioned in the second quadrant of the statement rating map with a high average rating on importance but low average rating on feasibility. So in the experts’ opinion this challenge is also quite important, but it seems that there are no feasible solutions yet. Examining the statement clarifies this emphasis. To enable a distributed conversation across contexts is related to research in the field of e.g. computer supported cooperative learning. Even if the complex technology mainly coming from the field of mobile and ubiquitous computing is there, it still needs to be utilised in the learning context, which requires additional research efforts also within the field of mobile learning. In addition to the valuable emphasis, the approach also produced a problem cluster map representing the mobile learning domain concepts based on the similarity of the problem statements identified. The main concepts that characterise the educational challenges mobile learning has to cope with are “access to learning”, “contextual learning”, “orchestrating learning across contexts”, “personalisation”, and “collaboration”. The minor domain concepts are “technology and technology adoption” and “limitations for learning”. The produced map can also be used to relate the emerging problem clusters within the overall domain.

The map shows that the clusters “access to learning” and “contextual learning” appear to be independent domain concepts, as they are individually positioned beyond the centre. The other clusters seem to be more closely related and positioned near to the centre. The mapping shows that the “orchestrating learning across contexts" cluster is the central concept within the domain. This indicates that orchestration is the link between the different concepts within the domain of mobile learning. Both the "collaboration" and the "technology and technology adoption" cluster are positioned in close proximity to the central concept, illustrating that the covered problem statements need to be considered when dealing with orchestration and vice versa. The clusters of "personalisation" and "limitations for learning" are positioned a little bit further away from the central concept and thus do not need to be considered equally when orchestrating learning through mobile learning. The same applies for the distant clusters "access to learning" and "contextual learning".

Focusing on the spatial extend of the single problem clusters, reveals that educational problems covered by the clusters "access to learning", "contextual learning", and "orchestrating learning across contexts" are in most cases only loosely related to each other. The mentioned clusters cover a wide problem space. In contrast the other clusters, especially "technology and technology adoption", cover a relatively narrow problem space with closely related problem statements. On the one hand this underlines that the main domain concepts cover a diversity of educational problems and it might be useful to put more effort on a more finely granulated distinction in order to make further analyses easier to handle. On the other this fact shows that these concepts are still a major point of discussion and there is no agreement on a clear definition related to mobile learning.

2.5 Conclusions

The presented expert concept mapping study provides new insights on mobile learning and the educational problems that underpin the expectations on it. Especially the identified domain concepts contribute to the discussion about the key characteristics of mobile learning, while clarifying the major educational problems that can be addressed by mobile learning. Still the paper outlines only the major findings of the conducted study. The data collected as well as the results obtained from the concept mapping approach allow further profound analyses on single or multiple domain concepts or specific educational issues and their correlation to others. Furthermore the results can also be used to provide guidelines for upcoming discussions on the theoretical and technical developments within the domain of mobile learning. These aspects will be addressed in future work.

Part III

Formative Studies

Chapter 3

Mobile authoring of open educational resources for authentic learning scenarios

The proliferation of smartphones in the last decade and the number of publications in the field of authoring systems for computer-assisted learning depict a scenario that needs to be explored in order to facilitate the scaffolding of learning activities across contexts. Learning resources are traditionally designed in desktop-based authoring systems where the context is mostly restricted to the learning objective, capturing relevant case characteristics, or virtual situation models. Mobile authoring tools enable learners and teachers to foster universal access to educational resources not only providing channels to share, remix or re-contextualize these, but also capturing the context in-situ and in-time. As a further matter, authoring educational resources in a mobile context is an authentic experience where authors can link learning with their own daily life activities and reflections. The contribution of this manuscript is fourfold: first, the main barriers for ubiquitous and mobile authoring of educational resources are identified; second, recent research on mobile authoring tools is reviewed, and 10 key shortcomings of current approaches are identified; third, the design of a mobile environment to author educational resources (*MAT for ARLearn*) is presented, and the results of an evaluation of usability and hedonic quality are presented; fourth, conclusions and a research agenda for mobile authoring are discussed.

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3.1 Introduction

Situated learning Brown et al. (1989) stress the importance of knowledge and skill acquisition in the same context in which they need to be performed; leading also to the concept of communities of practice Lave and Wenger (1991). While some educational media simulate real world environments with 3D-visualizations or micro-worlds several authors have stressed the difference between a simulated environment and authentic experiences in the real world **?**, **?**. Rule **?** clusters authentic learning into four themes: (1) real-world problems that engage learners in the work of professionals; (2) inquiry activities that practice thinking skills and metacognition; (3) discourse among a community of learners and (4) student empowerment through choice. The seminal article from Herrington & Oliver **?** identifies a number of design guidelines for situated learning activities like the need to provide authentic tasks and problems as also to support the change of perspectives.

With the availability of mobile technologies new potentials for the design and creation of authentic and situated learning materials have emerged **?**. Lombardi and Oblinger **?** identify mobile devices as one of the key technologies to support authentic learning with information access and data collection during field-based investigations. On the one hand learning support with mobile devices has aimed to increased universal access to advanced learning opportunities on the other hand the creation of learning materials in context and the documentation of authentic learning experiences have been researched. Nevertheless there are still many restrictions for the authoring support of authentic learning resources on different aggregation levels. Several research projects have demonstrated the potential of using mobile and ubiquitous devices to capture contextual information **?** and recording real-life experiences **?**, **?** but this potential has remained underexploited for the process of mobile authoring of learning resources.

Within this article we refer to "Mobile Authoring" as the process of content creation on different levels of aggregation by using mobile technologies. Kinshuk & Jesse **?** discuss the relevance of mobile authoring when capturing learning where and when it occurs. Additionally, they stress the lack of learner generated content in reusable learning objects authored for e-learning, especially with timely, relevant, and location aware examples. This manuscript reports about an analysis of existing mobile authoring solutions and the development and evaluation of a new mobile authoring tool for open educational resources. In the next section we report about related work and discuss shortcomings of current mobile authoring tools. In section 3 we introduce the Mobile Authoring Tool for ARLearn (*MAT for ARLearn*) that we have build aiming at authentic learning environments and the related authoring activities as also the shortcomings of analyzed tools. In section 4 we introduce an evaluation of usability and hedonic quality of the *MAT for ARLearn* . Section 5 discusses these results and limitations of the work. Last but not least we discuss future research.

3.2 Motivation and related work

Authoring learning resources is currently still a process that is generally conducted in front of a desktop computer making it hard to capture real-life experiences related to the actual learning situation. Most of the current authoring environments are desktop solutions that enable the deployment of the authored learning materials to mobile devices **?**, **?**, **?**, **?**, **?**, **?**, **?**, **?**. In this scenario, the user authors an educational resource surrounded by blank walls and situated in front of a computer screen. Authoring educational resources in a mobile context is a more authentic activity that provides access to real-life experiences, which are otherwise not easy to capture. For instance, when creating a learning resource about the architectural design of a building in the physical environment and context in which the building is located, the created learning materials and documentation are expected to be very different from the materials designed on a desktop computer. The creation in-situ and perception of relevant affordances and details is expected to impact the design of instructional materials as also the learning resource selection.

Remix and re-contexualization are key practices within the field of Open Educational Resources (OER). The combination of authentic learning scenarios and mobile authoring facilitates the connection between real-world locations and digital learning resources. Therefore the reuse and re-contextualization potential can be even larger than in traditional technology-enhanced learning scenarios. Nevertheless, different authors are skeptical on the assimilation and progress of remixing and re-contextualization practices from educators' side. Amiel **?** concludes that remixing learning resources is still not mainstream in education. Collis and Strikjer **?** report little success with bringing instructors close to an actual authoring process: "instructors do not have the time, interest, or skills". The proliferation of smartphones and the familiarization of new generations with mobile technology are bringing students and educators closer to an authentic and contextualized authoring process and to support reuse and remix of earlier developed resources.

The work from Mugwanya and Marsden **?** reviews mobile learning content authoring tools from 2002 to 2009. The authors categorize these tools according to technology used, pedagogy and usability dimensions. They summarize that the majority of the tools are developed with the goal of being integrated into Learning Management

Systems (desktop computer) and stress the need to develop mobile authoring tools that empower users to author content for use in mobile environments. More recently, several authors **?**, **?**, **?**, **?**, **?**, **?**, **?**, **?** have proposed solutions for desktop-based authoring of mobile content. These studies report about functionalities like the preparation of routes in maps, the binding of content to QR codes, or language learning content created on mobile devices to be later deployed for mobile learning support. Nevertheless these learning contents are mostly authored in front of a computer screen outside of the real context in which the mobile learning intervention is conducted later.

In contrast to desktop-based authoring, we have conducted a review of existing tools that support the mobile authoring of learning resources. There are different models classifying learning resources according to their granularity **?**, **?**. In the following, we will review mobile authoring tools aiming to shed light both on the granularity of mobile generated learning contents, and, what features do mobile authoring tools provide to foster universal access to existing learning resources.

3.2.1 Review in mobile authoring tools

The underlying search was conducted utilizing the online research repositories of the Association for Computing Machinery (ACM), the publisher Springer, Google Scholar, as well as the IEEE Computer Society. The focus on these repositories is reasonable as they cover a sufficiently large number of relevant publications. Within the ACM digital library an advanced search was performed in late January 2014 querying all articles of type journal, proceeding, or transaction that had been published since 2005 when mobile phones became more popular, and matching the keywords "authoring AND mobile" as part of the title. The query revealed 8 results whereof 4 were appropriate. As this query did not report enough results, a second search in the full-text matching the keywords "authoring AND mobile AND learning" was performed. The query revealed 1051 results where the first 30 occurrences ordered by relevance were selected. These 34 items were filtered by title and/or abstract. The rest of the repositories where analyzed analogously as illustrated in figure 1 The 24 resulting articles were fully analyzed and desktop-based authoring tools were discarded. This review has resulted in eight authentic mobile authoring environments listed in the appendix "Authoring tools in mobile context". For a more in-depth analysis of the mobile authoring tools identified in the literature review we have compared the different granularity levels that they support in their authored educational resources. As a basis we have used modular content hierarchy from learning objects introduced by Duval & Hodgins **?**. The result of this comparison is synthesized in Table 1. Resources that have a low

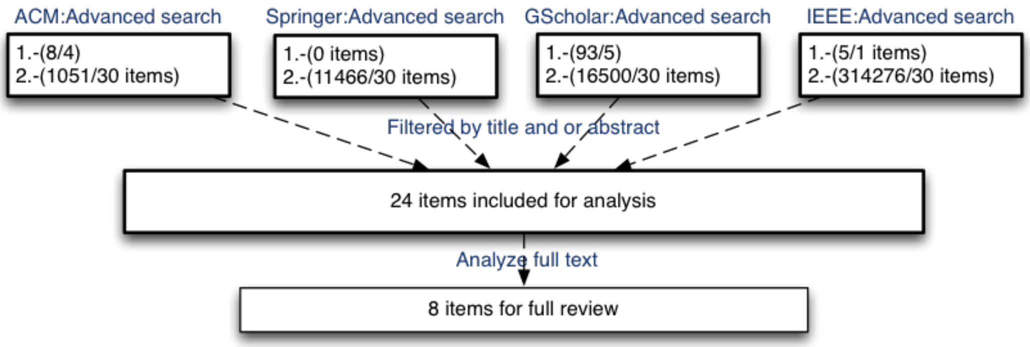


Figure 3.1: Mobile authoring tools review procedure

Table 3.1: Modular Content Hierarchy in mobile authored OER

	Raw data media elements	Information objects	Application objects	Aggregate Assemblies	Collection
Mobile Autor	Text	Multiple choice question, fill in blanks question	List of questions	-	-
RAFT	Pictures, annotations	Learning objects (aggregation of pictures, annotations, content metadata and context metadata)	-	-	-
StoryKit	Pictures, text, drawings, audio files	Page, that is, text enriched width multimedia	Book/Story, an aggregation of pages	Bookshelf, an aggregation of books	-
MPAS	Image, video, text	Multimedia slides	Presentation, aggregation of slides	-	-
MAAIMS	Audio, video or picture	Learning Object	-	-	-
Quizzer	Text	Multiple-choice question	Quiz	-	-
mProducer	Video clips	Learning Objects composition of video and context metadata)	Stories (aggregation of learning objects)	-	-
MoVie	Video, text	Video clip objects	Stories (aggregation of videos)	-	-

granularity, such us raw media elements are highly reusable. Raw media elements include, pictures, text in the form of annotations, audios, video clips, metadata about content, metadata about standard (LOM, SCORM), or metadata about the context (GPS coordinates). *Aggregate assemblies* and *collections* have higher level of granularity but they are least reusable.

The content taxonomy presented in Table 1 shows that all mobile authoring tools populate two to four levels of granularity. None of the mobile authoring tools populates the level of *collection* in the content taxonomy. This fact indicates that so far, content authored in mobile context is not created to be part of extensive collections, but rather to be integrated in units of lower granularity. An argument for this is the lack of available tools supporting remix of learning contents.

The analysis of these articles has resulted in the identification of 10 limitations (L1-L10) of mobile authoring tools with regard to universal access of content authored in a mobile context:

1. Sharing functionality. Authoring tools must feature sharing of authored educational resources in order to foster reuse and facilitate the expansion. Only one of the presented tools allows the sharing of resources created via E-Mail (*StoryKit*).

2. Remix support: Remixing allows authors to reuse educational resources and their rearrangement within new application contexts. Only two of the analysed tools provide support to remix resources (*Quizzer* and *Mobile Author*). While the two tools only allow remix on the *information object* level, remix features should be provided on different granularity levels to exploit the full potential of sharing of learning resources.

3. Recontextualization: Recontextualization is the transfer of a learning resource from one context to the other. While related concepts like repurposing **?** focus on the change of educational context, for the mobile authoring of learning resources for authentic learning scenarios the re-contextualization from one location to the other is important. The tools *MAAIMS* , *Quizzer* , *RAFT* and Producer support this type of re-contextualization.

4. Editing: Editing of educational resources benefits the adaptation of contents, context, and the rearrangement of the learning objects. Mobile authoring tools should provide mechanisms to support edit of educational resources. Some tools feature edit of the content (*StoryKit* and *Mobile Author*). MMAIMS feature edit of content metadata, and others feature edit of context metadata (*Quizzer* and *RAFT*).

5. Search functionality: Mobile authoring tools should provide mechanisms to

support allocation of educational resources from internal or/and external repositories **?**. Search of educational resources should not only be indexed on the name, description or owner of the educational resource, but also, indexed on the dimensions of the mobile context Specht (2009), namely, location, time, environment, relation and artefact identification. Hence, mobile devices can facilitate context related search of OER based on the location, time/date when the resource is useful or depending on the people or objects closer to me in a specific moment.

6. Sharing license support: Licensing is an important feature when sharing and reusing mobile content. Recent case study **?** implementing remix of OER for language learning highlights the selection of suitable licences as key consideration: "When remixing resources a series of considerations have to take place, which are not necessarily at the forefront in a traditional process of design. First off, one needs to be sure to select resources with more open licenses." Hence, the license model needs to support this remixing. Creative Commons has the right tools in place to flexibly support remixing of content. None of the presented tools (See Appendix) features any license assignment for authored content.

7. Learning Object standard support: The implementation of Learning Object Metadata (LOM) standards facilitates content indexing and benefits the integration of OER across Learning Management Systems. Of the analysed tools three support the IMS LOM or SCORM standard: *MAAIMS* facilitates the creation of standardized learning objects (IMS Content Packages and standardized learning activities (IMS Learning Designs) (IMS Learning Designs; *RAFT* implements SCORM.

8. Availability in open app markets: Mobile authoring tools should be available in open app markets as an approach to facilitate universal access to authoring tools. *StoryKit* is the only mobile authoring tool available in open markets.

9. Use of sensors: Some of the apps use different sensoring functionalities to support the contextualization and improve the quality of the learning resources. *Quizzer* uses the compass to serve content based on the orientation. In authoring mode, *Quizzer* records the orientation of the user to contextualize the resource. Moreover, *Quizzer* supports tagging of learning resources with the user's identifier on creation time providing some control on the ownership of the resource. Likewise, *mProducer* uses an accelerometer to measure the excessive amount of camera shaking recording a video, with the aim to filter blurry and unusable recordings.

10. Interoperability. None of the tools reviewed facilitates the interoperability

and exchange of educational resources among different mobile authoring tools.

The above-presented summary shows that there is no ideal mobile authoring tool implementing all the necessary features to exploit universal access. While the availability in open app markets will be targeted at a later stage, we have taken the limitations revealed in the from the scientific literature review into the design of *MAT for ARLearn* .

3.3 Design of the Mobile Authoring Tool for ARLearn

MAT for ARLearn has been designed considering the limitations enumerated in the previous section. This tool aims to provide an open environment to facilitate any user (teacher or student) to author, share, edit, remix and recontextualize educational resources to foster universal access. Hereby we describe how *MAT for ARLearn* was designed and which of these shortcomings are covered.

3.3.1 ARLearn: Cloud-based platform for mobile serious games

The Mobile Authoring Tool has been built upon ARLearn framework, an open source platform for authoring mobile serious games, available under the GNU Lesser GPL license Ternier et al. (2012b). ARLearn is accessible for the community as a cloud based solution where authors can, without cost, create content and deploy this content to mobile devices. Approx. 450 users have used the authoring environment to create games resulting in approx. 600 active games on the platform cloud. As illustrated in Table 2, learning resources in ARLearn are classified according to four different granularities in the model of content hierarchy **?**. We will further describe these objects providing some examples in the scientific literature where this platform has been used. ARLearn was extended with an open repository where users can make games open, license it properly and share these with their peers. ARLearn has ben used in several authentic learning scenarios:

- Recently, Schmitz et al. **?** investigated role-playing on helping behavior with a mobile learning game to train basic life support and cardiopulmonary resuscitation. With this game they aimed at improving willingness to help in case of emergency (Figure 2).

Table 3.2: Granularity of learning resources in *MAT for ARLearn*

	Raw data media elements	Information objects	Application objects	Aggregate Assemblies	Collection
MAT4ARLearn	Pictures, text, drawings, audio files	Audio item Video item Multiple-choice Text item	Game	Set of games	

- The Mindergie games have been designed and tested at a university campus in the context of an energy conservation pilot **?**. The goal of these games is to provide incentive mechanisms to decrease the energy consumption at the workplace. Every week players were given information, tasks and challenges, e.g. a video that provides the use with hints on how to consume less electricity.
- In collaboration with the United Nations Refugee Agency **?**, use cases for crisis situations were developed. These cases feature a social context through role-playing and typically zoom in on crisis situation like a hostage taking scenario. In this game employees are trained on how to react in such a situation. A game here is typically place in 5 phases: notification of the incident, assembling the team, planning, responding and negotiating. During the game players receive message according to their role. The head of office role will get a phone call from a journalist, while the staff welfare member needs to answer a call from a distressed family member.

The desktop-based[1] authoring environment for ARLearn (Figure 3) features the creation of games, teams, players, roles, items, and the dependencies among them. Moreover, it implements the Creative Commons (CC) licensing policy at the level of games (*application objects*) facilitating share and reuse across users. The games presented above are licensed under the CC attribution license. In the next section we describe the design and development of the *MAT for ARLearn* .

3.3.2 *MAT for ARLearn*

The Mobile Authoring Tool complements the ARLearn desktop-based environment. Hence, a mobile game author can wander around creating items and synchronizing

[1]ARLearn desktop-based authoring environment. http://streetlearn.appspot.com/

(a) Users had to allocate the defibrillator at the school and use it to save the victim.

(b) Users were instructed on the steps to follow in a cardiac arrest scenario. After the exercise, they were prompted to report the state of the victim.

Figure 3.2: Training cardiopulmonary resuscitation in schools with ARLearn **?**.

real world artefacts with game content. *MAT for ARLearn* has been designed starting a "Mobile Authoring" branch [2] from the last release of the open source code available for the ARLearn mobile client Ternier et al. (2012b). This procedure has facilitated the reuse of the already existent interfaces to access the backend via RESTful web services and the objects persisted in Google Appengine tables. The design of the tool has been performed adding functionality to the existing client following the next steps: first, we implemented the functionality to create a new game. Until now, it was only possible to create games from the desktop-authoring tool. These games are the containers of items; second, we implemented the functionality to create items so that users can create text items, video item, audio item and multiple-choice item in context recording or taking pictures with the mobile device; third, we perform the scientific literature review and identified the ten limitations for universal access; finally, these shortcomings were analysed and covered as illustrated in (Appendix II).

The *MAT for ARLearn* features three main approaches to foster ubiquitous and universal access to educational resources: 1) an author can create and contextualize new content; 2) an existing game (or an item) can be recontextualized to a new environment; 3) licensing selection is supported to promote the reuse, revision, remixing, and, redistribution of educational materials as open educational resources

[2] *MAT for ARLearn* source code. https://code.google.com/p/arlearn/source/browse/?name=MobileAuthoring

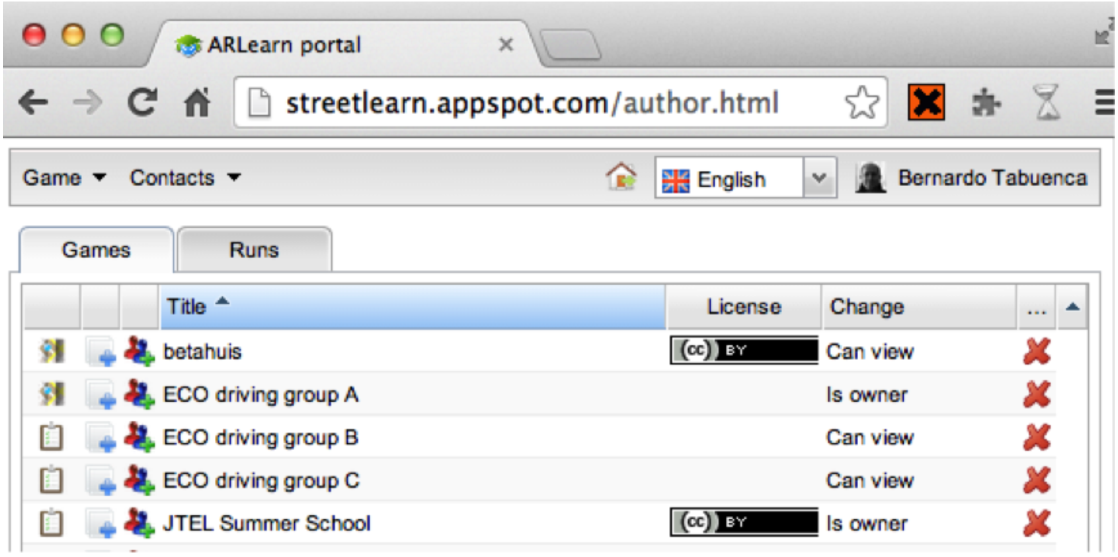
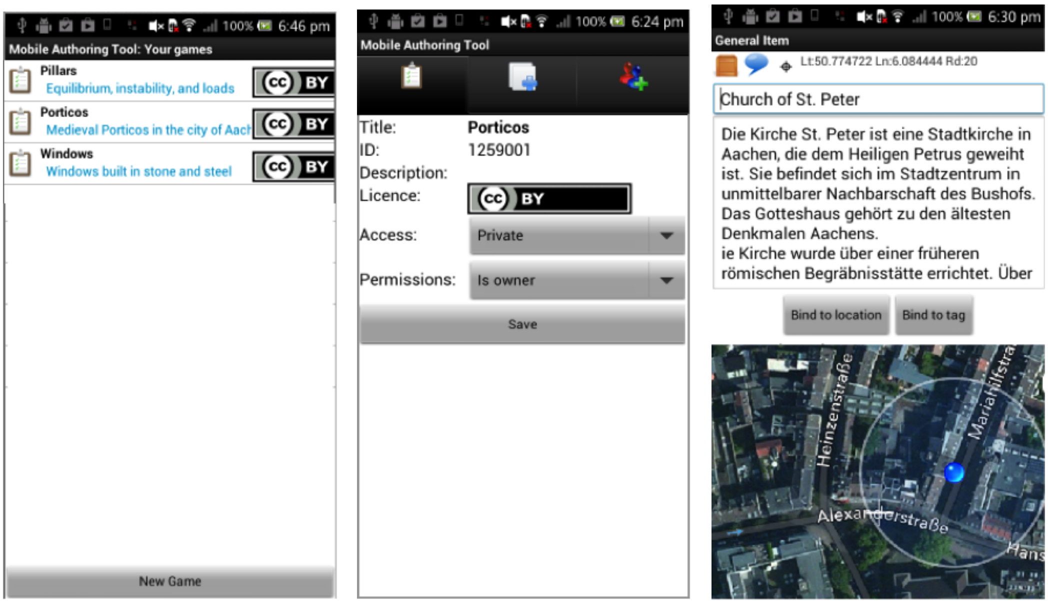


Figure 3.3: Desktop authoring environment in ARLearn

(OER).

The *MAT for ARLearn* features the "My Games" view as the starting point. Figure 4a shows the three games that the user authored for each of the architectural objects he is interested in; Figure 4b illustrates the "Game View" where the user can edit the resource and assign a licensing policy to share it. Clicking on the "item tab" (middle one) the user accesses the items that form this game. The author has the option to contextualize the content by binding it to the current coordinates, or by binding it to an existing QR code. Figure 4c illustrates the case of a user that has created a narrator item (text item) about the Church of St. Peter as an aggregation to the porticos game (*application object*). As he is located in an authentic environment, for example in front of the church and staring at the portico, the description inspired on the real situation is completely different from the one he would create sited on his desk and watching a picture on the screen. As the user is in a mobile context, he can also contextualize the educational resource to the current location. In this case, the user can contextualize the item with the dimension location by registering the current coordinates and radius (See top of figure 4c) clicking on the "Bind to location button". The user can also contextualize the item with the dimension artifact identifier whenever there would be a QR code next to the church. By clicking on the "Bind to tag" button, he would scan the code and the educational resource would be attached to that identifier. Next, he can edit the resource to indicate the CC license that should be assigned to the item.



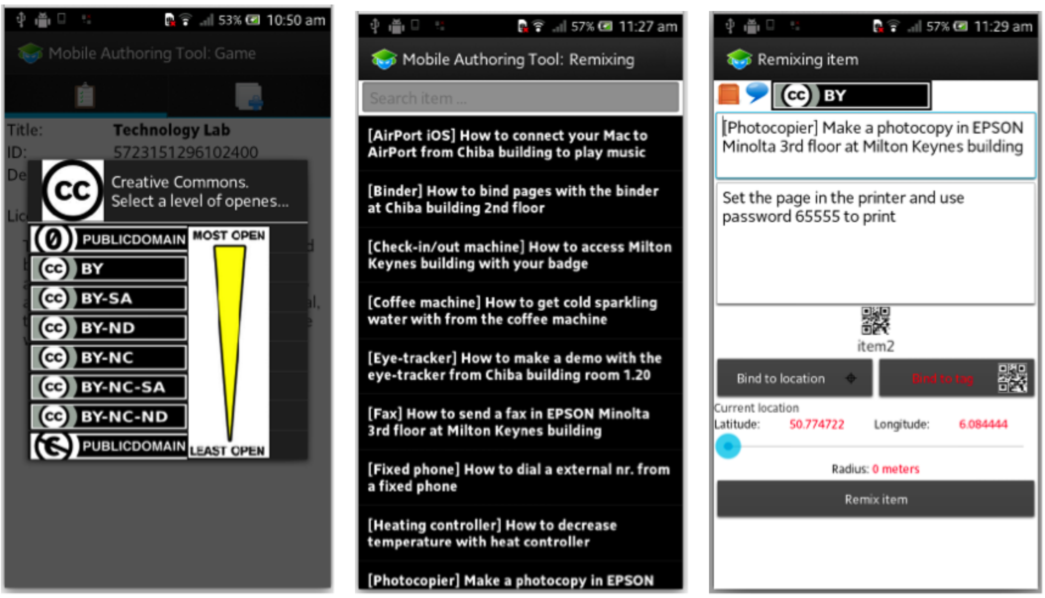
(a) "My games" screen lists games created by the author **(b)** Authoring games screen **(c)** Contextualization of educational resources

Figure 3.4: Mobile Authoring Tool for ARLearn interface

3.3.3 OER remix in mobile context

Instead of creating a new resource from scratch the user can search within the already existing OER to clone it and aggregate it without making any modification (remix), or, adapting it to the new context by updating any of the dimensions of the mobile context Specht (2009) (recontextualizing).

The *MAT for ARLearn* enables the user to issue a mobile OER search, to assess and to reuse an item in a new context. Users can also extend their game script by reusing a single item rather than reusing a game as a whole. Recontextualizing and remixing needs an infrastructure in place that supports flexible access to content. A search infrastructure must enable searching for content corresponding to different granularities. ARLearn supports searches from two granularities in the modular content hierarchy, namely, *information objects* (games), and *application objects* (items). Users can author games and items, and make them open access to the community. Figure 5a illustrates how licences are presented in descendent level of openness according to **?**. Via this infrastructure, the *MAT for ARLearn* provides access to search functionality for items as well as for games as a whole when being in a specific context.



(a) Select level of openness for a new game **(b)** Search in already existing items for remix **(c)** Remix and recontextualization of a "text item" with location coordinates or artefact identifier

Figure 3.5: Remixing and recontextualizing items with the *MAT for ARLearn*

Figures 5b and 5c illustrate a case remixing and recontextualizing educational resources in a mobile context:

- Remixing. The user is interested in including a video on the architecture of the Cathedral in Aachen. Instead of creating it, he uses the search tool (Figure 5b) to look for already existent educational resources. He finds an educational resource from a guided tour that somebody had previously shared. He clones the item and aggregates it as a whole into the game, without modifying it (Figure 5c).
- Recontextualization. In this case, the user is interested in including a multiple-choice-question to assess knowledge on medieval porticos. Instead of creating it he uses the search tool (Figure 5b) to look for already existent assessments on porticos. He finds one that was previously bound to the porticos at the

Cathedral of Cologne. He clones the item, modifies the context by binding it to current coordinates and radius (Figure 4c), or a QR tag (Figure 5c), and aggregates it into the game.

The *MAT for ARLearn* features a new quality for recontextualization. This tool provides mechanisms to recontextualize educational resources in different dimensions like "location" and "artifact identifier" via sensors. Making content appear when the user enters a zone, is an example of binding the content to location using the GPS of the device. QR codes enable the identification of real world artifacts using the camera and the QR reader of the device. Binding content to a QR code is thus a means to synchronize them with the artifact. Image recognition, or, text recognition tags are similar approaches to recontextualize OER with the artifact identifier dimension. ARLearn allows for tagging artifacts with Radio Frequency Identification (RFID) tags or bar codes (QR, EAN-13) as an easy and open procedure to enrich physical spaces with machine-readable tags.

3.3.4 OER licensing policy definition

Creative Commons fosters share and reuse. An easy to use and legally interoperable license is a critical component for the OER movement **?**. Figure 6 illustrates how OER can be legally remixed with other OER. It is important to highlight that when implementing cross-license remixing, only one third of CC's own licenses are compatible. These combinations are illustrated in figure 6 with the smileys. When a game is created with open licence (different than CC-BY-NPD), all items will inherit this license by default. Nevertheless, licences from items can be consistently updated whenever both game and item licences are compatible. If a game specifies a No Derivatives (ND) licensing attribute, its items will not be searchable or reusable. In such case only the game as a whole can be reused. When a user reuses an existing game, the original author will be appropriately credited. A user that reuses a ShareAlike (SA) licensed game will not be able to restrict the access rights. Furthermore, an interesting situation occurs when a user reuses an item: if a user reuses a video that should be SA, the entire game becomes SA.

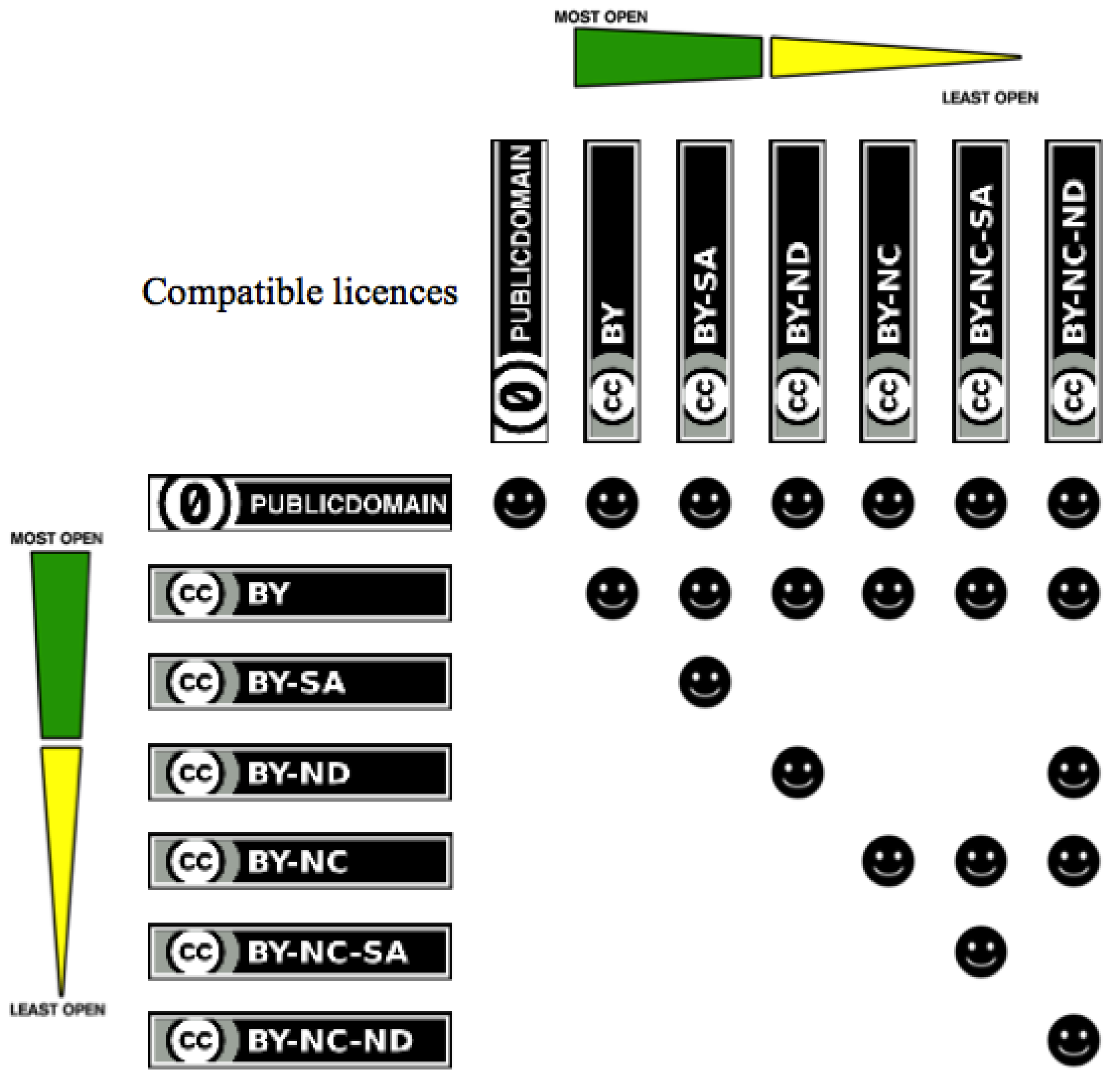


Figure 3.6: Remix compatibility according to spectrum of freedom in Creative Commons licenses **?**.

3.4 Usability Evaluation of *MAT for ARLearn*

Authoring contents with mobile technologies must be accomplished in an efficient and intuitive way that facilitates the user to create new resources in any specific context. Quantifying the usability of the Mobile Authoring Tool is key to determine how suited is the system to be used across contexts. We have conducted an evaluation of usability and hedonic quality of the *MAT for ARLearn* tool. In this section we present the methods, instruments and results of the evaluation.

3.4.1 Method and participants

This study was conducted in February 2014 at the Open University of The Netherlands. An invitation was distributed via E-Mail with the aim to recruit participants for an experiment within the Technology Enhanced Learning Lab. Seven employees (AVG age = 34, male, all smartphone owers) voluntarily reacted to the invitation. The experiment was performed during one day with a time limitation of 30 minutes per participant and the participation was not rewarded.

In the instruction phase the participants were introduced the concept of "mobile authoring" as the process of producing content by building up materials in the authentic context where these artifacts or persons are normally interacting, in order to build learning ecologies. They were prompted to create a welcome game for new employees at the lab that should describe relevant resources at the workplace like technological equipment (scanner, heating control, fax, photocopier, WI-FI, coffee machine, etc.), people (room-mates, project colleague, etc.), and descriptions on how to get acquainted with the work at the institute. We suggested producing resources with a specific purpose so they can be further reused by forthcoming participants (e.g. a new employee, labour risks at your workplace, measures for energy saving at workplace, etc.).

As illustrated in figure 7, the mobile authoring phase comprised the creation of one text item, one video item, one audio item, and one multiple-choice question that people could use to collect the assessments for these artifacts (e.g. quality of the printer, strength of the WI-FI signal in specific meeting rooms), and remix one item by choosing it from the list of shared items and edit it for reuse. Participants are asked to contextualize items by binding them to tagged artifacts (QR codes) or coordinates (GPS location). Likewise, participants were able to recontextualize items by remixing already tagged artifacts and editing the information of the context. In the last phase, participants were prompted to fill in a usability questionnaire and provide qualitative input about the hedonic quality of the tool.

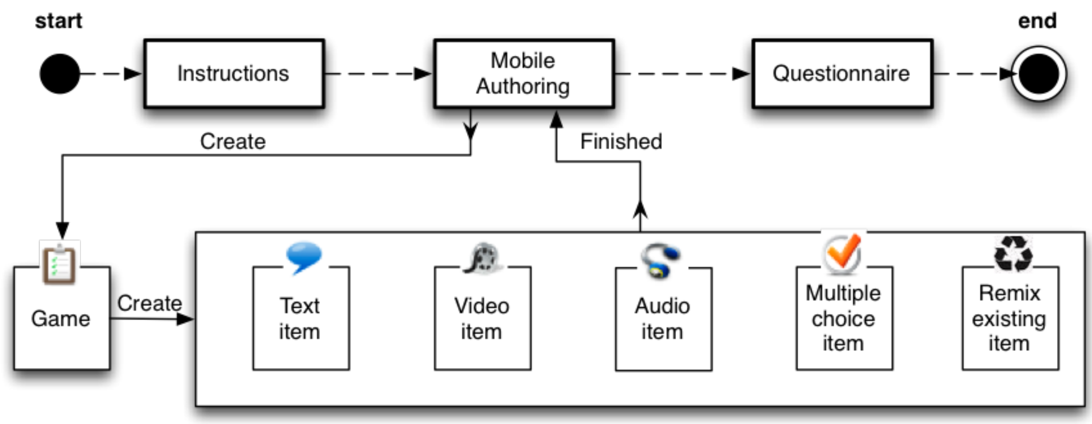


Figure 3.7: Flow of the experiment. UML-State diagram

3.4.2 Instruments

The material for the study consisted in a first introduction of the experiment with a set of instructions to be read on paper, an Android smartphone (Sony XPeria S) with the *MAT for ARLearn* installed in it, and a desktop computer for accessing the questionnaire and the Reactiondeck toolkit. *MAT for ARLearn* requires an Internet connection to synchronize resources with the ARLearn backend.

The System Usability Scale (SUS) was used for the evaluation of the usability **?**. The SUS scale consists of 10 questions with a five-point Likert scale, where item directions are changed in each question. The results of the survey were recorded in an online questionnaire. Based on the current literature, a SUS score above 68 (SD:12,5) is rated as usability score above average. This analysis have followed the recommendations from Sauro **?** so that the results can be mapped and benchmarked against 446 previous studies and 5000 individual responses.

Hassenzahl has discussed the limitations of taking only into account usability and he has proposed in addition to take into account the "hedonic quality" **?** of an interface. Hedonic quality is defined as the non-task related quality dimensions like "accessibility" or "originality". We employed the Reactiondeck toolkit developed by Benedek and Miner at Microsoft Research to assess these aspects **?**. These product reaction cards have been transferred to a digital version and published as Reactiondeck toolkit **?**. Thus, participants were asked to select 6 product reaction cards that describe the emotional appeal of the mobile applications best and provide arguments on the selection (See Figure 8). After choosing the cards, users were invited to argue in an open text box why did they selected that card.

Figure 3.8: Evaluation of hedonic quality with the Reactiondeck ?.

3.5 Results

Participants created (audio, text, video) resources to explain how to extend notebook's screen to a bigger display, how to setup the fax, how to get cold sparkling water from the coffee machine, how to use the badge to access different buildings or how to play a demo in the eye-tracker of the lab (Figure 5b). Participants created multiple-choice questions to rate the quality of the printer, how clean is the lab, or the quality of the coffee machine. Participants remixed items like the photocopier instructions that only differed in the password depending on the building within the campus, or scanner instructions that differed in some steps depending on the brand of the device, and plugging the display that differed on the operating systems of the notebooks.

3.5.1 Usability evaluation

The evaluation of the usability shows that *MAT for ARLearn* has a mean score of 80 (SD = 7.2), which is remarkably above average (SUS more than 68). Items 4 and 10 from the questionnaire were taken as subscale for learnability. Average learnability score was 17,81 where two participants (user 2 and 8) rated slightly below average. Items 1, 2, 3, 5, 6, 7, 8, 9 contribute to the construct usability where average score was 62,81 and only one participant rated below average (user 3).

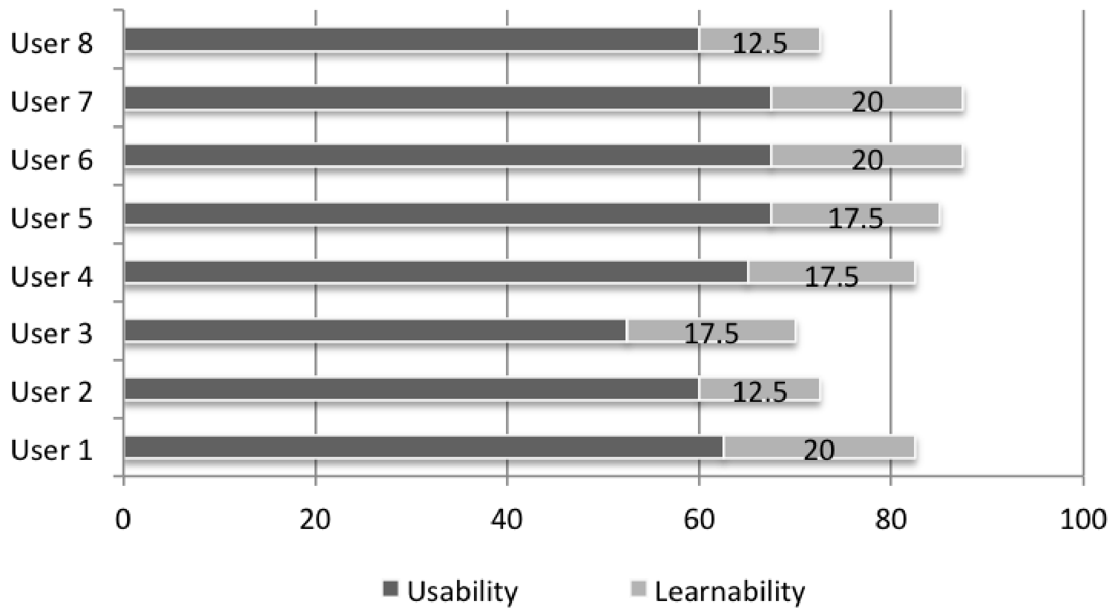


Figure 3.9: Evaluation of Usability and Learnability with the System Usability Scale (SUS) **?**.

3.5.2 Hedonic quality evaluation

The Hedonic quality evaluation harvests adjectives that define the interface and usability of the tool considered in terms of pleasant (or unpleasant) sensations. Figure 10 illustrates which were the most selected adjectives to determine the hedonic quality of the *MAT for ARLearn* . "Organized" and "Usable" were the most voted adjectives by the participants (n=4). E.g. regarding the organization users argued: "The distribution of items, icons and buttons within the screen is consistent", "The interface is clear, and there are not useless elements on the screen. All of them are self-explanatory". These adjectives highlight a suitable distribution not only of the functionality across screens, but also of the elements (buttons, images, text boxes, etc.) used within the screens. Regarding the "usability" participants argued: "The tool is intuitive and I feel confortable using it", "All choices for authoring are self-explained thus the tool is easy to use". Three participants selected "Easy-to-use" and two participants selected "accessibility" arguing "It is easy to get access to configuration procedures of artefacts through mobile devices". These adjectives reveal an appropriate usability of the tool since participants could intuitively navigate without instruction and based on what they felt to be necessary.

One participant highlighted the importance of providing open access to authored resources "It is nice to share knowledge with others". This comment recognises the

Figure 3.10: Tag cloud visualization for the measure of hedonic quality.

benefits of openly sharing knowledge as a way of actively promoting innovation, developing educational capacity and speeding up the processes by which researchers and academics review and build on each other's work. On the other hand, the willingness of users to share their identify tagging authored educational resources with a suitable licence keeps being a controversy. In fact, two-participants reported their reluctance selecting the card for "not-secure" and arguing that "The identity of the user might be in danger when sharing resources", "I am not happy sharing my identity when sharing content".

3.6 Discussion and Conclusions

The article has introduced the lack of authenticity in situated learning scenarios of desktop-based authoring systems in contrast to mobile-based authoring systems where resources can be enriched with users' context Specht (2009), *namely* , *location* , *time* , *environment* , *relation* and *artefact identification* . This manuscript proposes the use of mobile authoring tools not only as a solution to cover this gap, but also to foster universal access to educational resources. The review of scientific literature has revealed eight mobile tools for authoring of educational resources in a mobile context. These resources have been classified according to the Modular Content Hierarchy model **?** (Table 1) with the aim to identify the grain of their authored resources towards the definition and the levels they can aggregate. Based on an analysis of these tools we have recognized ten shortcomings (L1 to L10) mobile authoring tools should cope to foster universal access to educational resources authored in a mobile context (See Appendix II).

These features have influenced the design and development of the *MAT for ARLearn* tool. In contrast to the existing standalone tools reviewed in this manuscript, *MAT for ARLearn* has a scripting environment for mobile serious games for learning in the background. *MAT for ARLearn* has extended the state-of-art of authoring tools featuring 7 of the 10 limitations concluded in the literature review, namely, (L1) share, (L2) remix, (L3) recontext, (L4) edit, (L5) search, (L6) licence support, (L9) use of sensors. This tool features searching, editing and sharing of learning OERs via Creative Commons licences facilitating the remix of contents. Moreover, *MAT for ARLearn* features the creation and contextualization of educational resources on two of the dimensions of the mobile context Specht (2009):

- Location. Users can bind authored resources to locations. E.g. an audio recording on a specific architecture linked to the geographical coordinates (longitude, latitude, radius) of a church (Figure 4c). Location coordinates can be obtained via GPS sensors in mobile phones.
- Artefact identity. Users can bind authored resources to tags attached to physical objects. E.g. text instructions on how to use a photocopier linked to a QR code (Figure 5c). Barcodes or NFC tags are instances of artefact identifiers accessible via sensors in mobile devices.

Results of a usability evaluation have confirmed that the tool has usability above average and that users understand the functionalities of the tool. These findings are reinforced by the hedonic quality evaluation conducted. We believe that mobile authoring tools that allow for content sharing under open content licensed will be a key enabler for building an ecology of digital learning resources which are freely available in the direct environment of learners and which can be re-used, adapted and recontextualized. Moreover, both the measure of 'usability' and 'hedonic quality' presented in this manuscript, can be taken as a reference for forthcoming developments of authoring tools serving as a base for future quantified and qualified comparisons.

The review of authoring tools presented in this manuscript is limited to systems found in scientific literature. This research should be extended to the ones existing in open app markets (Android, iOS, Windows, Blackberry, etc.). *MAT for ARLearn* is currently in BETA version and will be released in the Google Play market as one more feature within the framework (L8).

In future research, we will develop and evaluate further features to (re)contextualize learning contents with the pending dimensions of the mobile context Specht (2009): time (e.g. a video recording on an specific historic which is only made available to appear on anniversary dates); relation (e.g. an educational resource that is only made available to appear when all the members of a group are together); environment (e.g. "whenever the temperature is higher than 40 degrees, play an audio item on measures to prevent dehydration").

Appendix

I Authoring tools in mobile context

Mobile Author **?** is a one of the very first mobile authoring tools. This tool contemplates the implementation of only text resources. Moreover, *Mobile Author* includes tutoring features to track student's progress and provides advice adapted to the needs of individual students. This tool was designed assuming that there are two roles, namely, the instructor and the student. In this case, the instructor is the one who authors the lessons and broadcast them to the students in the form of multiple-choice questions, fill-in the blanks and texts, so they can carry out the tasks.

The Remotely Accessible Field Trips (*RAFT*) project **?** is a framework for mobile authoring of learning content in context. The authors discuss the relevancy of contextual metadata for flexible access to learning objects, and, describe approaches for extending current metadata schemas with context metadata. *RAFT* makes use of context data to find appropriate use for adaptive learning on demand and personalized learning experiences.

StoryKit **?** is a framework for mobile authoring with which children can create original stories, or modify sample stories with their own photos, drawings, and audio. Stories are presented in the form of books. Books can be shared with teachers or colleagues by sending an email (through the mobile app) with the URL of the book in the server, so that the book can be later visualized in a web browser.

Multimedia Presentation Authoring System (*MPAS*) **?** produces multimedia e-learning contents for mobile environment. *MPAS* makes possible to create multimedia presentations that integrate diverse media types including images, video, sound, and texts for mobile devices. This proposed system provides an integrated authoring environment that enables authors to produce e-learning contents from media objects and edit or reconstruct existing presentations.

Mobile Authentic Authoring in IMS (*MAAIMS*), **?** captures authentic learning examples with the mobile device sensors (photo camera, video camera, microphone) which can be supplemented with location aware GPS coordinates and other descriptive metadata following IMS Metadata specifications. *MAAIMS* encapsulates these authentic learning examples and employs them as standardized learning objects (IMS Content Packages), and optionally as, standardized learning activities (IMS Learning Designs).

Quizzer **?** enables users to author quizzes in context. Quizzes can be created from scratch or based on existing quizzes. Users can extend or modify quizzes created by others, which will result in separate new quizzes. Optionally, the user can set the location and orientation context for the question. This can either be done manually by pointing on a map and adjusting the orientation value. It can also be done automatically by letting the GPS sensor determine the current location and using the compass for capturing the orientation. In *Quizzer* user collaboration is based on exchanging quizzes, scores, ratings and comments.

mProducer **?** enables everyday users to perform archiving and editing digital personal experiences from their camera-equipped mobile devices. It also includes sharing features. Nevertheless they do not contemplate remix and recontext.

MoVie **?** is a social media service that enables users to create video stories using their mobile phones. The staff of a Jazz festival used it for documenting arrangements. The aim was to use the videos for learning how to do things better next year. Supports video sharing and remixing. Moreover, it supports tagging videos by collecting contextual information based on the location of the device.

II Mobile authoring tools classification according to the 10 features for universal access to educational resources

	1.Share	2.Remix	3.Recontext	4.Edit	5.Search	6.License	7.Standards	8.Open app markets	9.Sensors	10.Interoperability
MAT4ARLearn	X	X	X	X	X	X	-	-	X	-
Mobile Author	-	X	-	X	-	-	-	-	-	-
RAFT	-	-	X	X	-	-	X	-	-	-
StoryKit	X	-	-	X	-	-	X	X	-	-
MPAS	-	-	-	-	-	-	-	-	-	-
MAAIMS	-	-	X	X	-	-	X	-	-	-
Quizzer	-	X	X	X	-	-	-	-	X	-
mProducer	-	-	X	X	X	-	-	-	X	-
MoVie	-	-	-	X	-	-	-	-	-	-

Figure 3.11: Mobile authoring tools classification according to features.

General Discussion[3]

Review of results

This thesis presented the results of the conducted research and development of ambient learning displays. The reported results were structured into three parts: the theoretical foundations, formative studies, and empirical findings. An elaborated conceptual framework and an extensive literature review explored the research field and laid the foundation for further research (**Part I**). Several formative studies informed the theoretical work as well as the design and development from different perspectives (**Part II**). Following up, empirical studies then evaluated respective ambient display prototypes (**Part III**).

Theoretical foundations

Chapter 1 outlined the vision of ambient learning displays – enabling learners to view, access, and interact with contextualised digital content presented in an ambient way. This vision was based on a detailed exploration of the characteristics of ubiquitous learning and a deduction of informational, interactional, and instructional aspects to focus on. Based on these aspects the main research question was formulated:

> *What are the effects of ambient information presentation on learning in a*
> *situated learning context within ubiquitous learning environments?*

To provide a theoretical foundation for the following research, relevant research findings, models, design dimensions, and taxonomies were examined. The result was a conceptual framework that defined ambient learning displays. The framework consists of parts dedicated to user and context data acquisition, channelling of

[3]This chapter incorporates discussions and conclusions from several publications.

information, and delivery of contextualised information framed in a learning process. Ambient systems were proposed as means of delivery. Based on the taxonomy of ambient information systems by Pousman and Stasko (2006) four design dimensions were introduced, incorporated in the framework, and applied whenever designing ambient display prototypes throughout the following research. The four design dimensions are:

- Information capacity determined by the amount of information presented by the system.
- Representational fidelity describing how the data is encoded.
- Notification level depicting the degree of user interruption.
- Aesthetic emphasis.

As first step on the research agenda towards ambient learning displays an extensive review of the literature on ambient displays was conducted. The first part of the review in **Chapter 2** depicted characteristics, classified prototypical designs, and shed light on the actual use of the covered ambient displays, their application context and addressed domains as well as the type of studies conducted, including the used methodologies and evaluation approaches to measure their effectiveness and impact. The review confirmed the following main characteristics of ambient displays as defined initially by Wisneski et al. (1998):

- Peripheral, unobtrusive, and embedded design addressing various senses.
- Utilisation of subtle methods in the periphery of attention.
- Focus on ensuring awareness of mostly non-critical information.

The presented prototypes were applied in personal, public, or semi-public contexts. In a personal context the displays were closely linked to individuals (or the individuals close proximity) with high emphasis on privacy. Addressed domains included leisure activities, health related issues, or information awareness. In a public context, the displays implemented a strong environmental link with low emphasis on privacy. Addressed domains included among others consumption and conservation of natural resources. Between the two levels in a semi-public context the covered displays linked to, e.g. workplaces or classrooms. Consequently, addressed domains included group collaboration, communication, or awareness. Single prototypes were also used within educational settings.

Several articles derived principles and guidelines for the design of ambient displays, some of which were already incorporated in the conceptual framework. The classification of the presented prototypes within the framework revealed that the main source to acquire relevant information is sensor data, monitoring user activity and behaviour within the environment. The gathered information is then to a great extend channelled harnessing the learners' sense of vision. In terms of framing into a learning process, most prototypes do not go beyond the factual knowledge dimension, while addressing lower cognitive processes. This result is in line with the initial expectation to find a large number of ambient displays that simply represent information rather than supporting more complex cognitive processes.

The methodological analysis of the reviewed articles highlighted a plethora of methodologies and evaluation strategies used in the different types of study conducted. The whole array of available instruments was applied in the course of the complete research cycle (preparation, implementation, analysis) covering pilot studies, field studies, or a combination of both. In general, the evaluation of ambient displays was described as difficult across the reviewed articles. The following issues were identified as most critical:

- Unobtrusive collection of necessary data without additional user distraction.
- Usefulness of evaluation when user interest is not stable.
- Evaluation of the usefulness, benefit, and comprehension.
- Adaptation of heuristics to evaluate usability and effectiveness.

The literature review continued in **Chapter 3**. This second part focused on the actual use of ambient displays in a learning context. The purpose was to assess ambient displays with an explicit or implicit learning purpose and the classification of respective prototypes on the basis of an extended classification framework. The classification framework included three perspectives:

- Informational and interactional design of the prototypes.
- Research objectives and results of the reported empirical studies.
- Deducible instructional characteristics.

To describe the informational and interactional design, the introduced design dimensions were used. For the instructional characterisation the concept of situational awareness as defined by Endsley (2000) with the three levels perception, comprehension, and projection as well as the research variables of interest when providing instructional feedback by Mory (2004) were used. Thus the incorporated classification criteria were: level of situational awareness, complexity, timing, error analysis, and learning outcome.

The classification of the ambient display prototypes according to the introduced design dimensions showed that the majority of prototypes handled only a low capacity of information, were reluctant when it comes to the level of notification by just making aware, utilised all available representational means from indexes to symbols, and put a medium emphasis on aesthetics.

Next the research objectives, reported results, and findings were analysed. The majority of articles targeted basic psychological effects, such as raise, enhance, or support awareness. Only some went beyond stating to trigger changes in behaviour or give direct feedback, calling for more research on concepts like persuasion, motivation, feedback, and behaviour change to lay the foundation for learning processes supported by ambient displays. Several papers focused on an evaluation of the displays design without evaluating learning effects explicitly. The missing focus on learning effectiveness opened up a research gap towards ambient learning displays.

The reported result can be classified into groups dealing with the user experience, functionality, design, and evaluation of ambient displays. In general, the displays were experienced positively and perceived as characterised. They fulfilled their intended functionality, especially providing information and presence awareness. To trigger changes in behaviour the displays needed to be engaging and motivating, e.g. by providing direct feedback. A minority of articles explicitly used ambient displays for learning, many more addressed learning implicitly.

Most reviewed prototypes addressed the lowest level of situational awareness, i.e. perception. It was noted that learning outcomes involving higher cognitive process capabilities were most effectively addressed by abstract information representations with at least simple verification feedback incorporating corrective error analysis. In contrast declarative or concept learning also worked with no feedback complexity and simple confirmatory error analysis. Other conclusion drawn were:

- Abstract representations are more effective on raising awareness, foster self-regulation, or increase behavioural impact.
- Feedback complexity, error analysis, and learning outcome increase with the situational awareness level.

In summary, the mapping of the corresponding prototypes with the introduced classification framework led to first general design implications, taking into account instructional characteristics. The framework proved to be suitable to draw conclusions on the effectiveness of prototypical variations in a learning context.

Formative studies

Chapter 4 described an explorative study conducted to inform the research of ambient learning displays. By asking domain experts the used concept mapping approach identified the major educational problems that can be addressed by mobile learning and clustered these problems into domain concepts that contribute to a definition of mobile learning. Although the study targeted on the mobile learning domain, the results were in a broader view also considered valuable for the ubiquitous learning domain. Especially the following identified problem statements were related to the mobile and the ubiquitous learning paradigm:

- Access to learning resources and learning opportunities without the restrictions of location, time and cumbersome equipment or facilities.
- Ability to discover and experiment in own context.
- The provision of access to knowledge in the context in which it is applied.
- Accessibility of information in relevant everyday life and work situations.

These statements were clustered in the following main problem cluster:

- Access to learning covering problems that are mainly related to the challenges of enabling learning in a mobile society.
- Contextual learning comprising problems that highlight the relation between learning and the context in which the learning takes place.

The identified educational problems and derived domain concepts reflected the claim of mobile and ubiquitous learning to enable learning across context, facilitating and exploiting the mobility of the learners. The emphasised issues mainly discussed learning activities and opportunities outside of formal settings with better contextualised and situated learning support. The results were used both as indicators for the research focus and as an instrument to validate research findings.

The results of two projects that informed the design and development of ambient learning displays were presented. The first project, presented in **Chapter 5**, elaborated and developed an infrastructure that supports energy conservation at the workplace. Therefore the infrastructure utilised existing services and included individual energy consumption information. The main idea was to make hidden consumption data visible and accessible for the people working in the building. The infrastructure implemented the following functionality in line with the presented conceptual framework, i.e. data acquisition and channelling of information:

- Inclusion of individual energy consumption information (device specific or personal level of detail.
- Aggregation of available information extending and enriching the overall energy consumption picture.
- Sensoring and logging to measure the effectiveness in terms of energy conservation and enable the prototypical evaluation.

Based on the supporting infrastructure, application prototypes to access and explore the information were developed. The prototypes were classified according to the presented classification framework. Regarding the instructional capabilities the developed prototypes went beyond the mere level of information perception. Instead, the addressed situational awareness demanded at least the comprehension of the available informational cues. To use the application prototypes efficiently even demanded to forecast and estimate the implications of the personal consumption behaviour. In terms of the used feedback characteristics, the prototypes provided simple verification feedback that could be more elaborated on demand. The timing was immediate, although the delivery of information was not happening in real-time due to technical restrictions. The feedback intended to convey at best relational rules as learning outcome, while not going beyond the confirmatory analysis of errors.

Besides measuring the effectiveness of the prototype, an informative study, a comparative study, an user evaluation, and a design study were conducted. The results indicated the general interest in the topic as well as the usefulness of the prototype in terms of estimation and concern about the individual energy consumption. Participants were especially interested in investigating and adapting their consumption patterns accordingly. The design study revealed a preference towards an indexical representational fidelity.

The second project, presented in **Chapter 6**, implemented a pervasive game to increase the environmental awareness and pro-environmental behaviour at the workplace. Based on a discussion of the theoretical background and related work, the game design and game elements were introduced. The presented evaluation results showed that a pervasive game is a promising approach to involve employees actively in the energy conservation of an organisation. Incentive mechanisms, such as rewards in form of digital badges, were less important. All game elements that contributed to knowledge building or that involved participants in problem solving or the development of own ideas (activity, action, challenge) had more influence on pro-environmental consciousness and pro-environmental behaviour. When asked about improvement suggestions, participants called for an engaging game design, multiplayer options, and personalised feedback.

Chapter 7 then described a lecture series that summarised the theoretical foundations. Furthermore, the chapter reported on a participatory design study conducted in the course of the lectures. The presented results showed a variety of usable ambient display types, possible learning scenarios, and specific design proposals towards ambient learning displays. The participants described different ambient display types, whereas the majority either utilised embedded display screens or billboards, converted existing technical appliances of daily use, or harnessed mainly visual appliances like glass, windows, or mirrors. The participants had difficulties describing concrete learning scenarios and respective ambient learning display design. The scenarios described by the participants mainly had one of the following objectives:

- Increase awareness of contextual information.
- Provide feedback on user action.
- Support the learning of languages or psychomotor skills.

Empirical findings

This first empirical study into the research and development of ambient learning displays was presented in **Chapter 8**. The first part of the study reported an intervention to initiate environmental learning and facilitate pro-environmental behaviour. The purpose was to examine the impact of ambient learning displays on energy consumption and conservation at the workplace, more specifically the evaluation of learning outcome and behaviour change. For the experimental treatments, prototypes were varied on two design dimensions, namely representational fidelity and notification level. The research questions were:

- Does the design of an ambient learning display influence the environmental learning outcome?
- Do the ambient learning display prototypes deployed lead to pro-environmental behaviour change?

The first hypothesis stated that using interruptive notification and symbolic representation should result in a significantly larger environmental learning outcome than using change blind notification and indexical representation. The results did not show evidence to support this hypothesis. The group with the interruptive and symbolic prototype design had the largest outcome, but the design variations had no significant influence on this.

When investigating the environmental learning construct's single components, namely the participants' environmental awareness, confidence, knowledge about consumption, as well as concern and conservation attitude, some supporting evidence for the hypothesis were found. The group with the interruptive and symbolic design showed the largest gain in confidence and awareness, indicating that this design lowered the awareness need and built up confidence to estimate the actual consumption and conservation potentials. On the other hand the group with the change blind and indexical design showed the largest gain in knowledge, suggesting that this design supported the examination and comprehension of the provided consumption information, saving tips, and conservation potentials. The group exposed to the change blind and symbolic design showed the largest gain in concern and conservation attitude.

The second hypothesis stated that independent of the display's design variation the sole deployment of ambient learning displays should facilitate pro-environmental behaviour change. Again there was no supporting evidence that the prototypes have an influence on the conservation activities performed. The results suggested that the prototypes deployed even had an opposite effect. Testing the single component mean differences across all participants showed that the deployed prototypes significantly influenced awareness and knowledge. So the prototypes did not facilitate pro-environmental behaviour but at least helped to examine, comprehend, and lower the awareness need.

The second part of the study, presented in **Chapter 9**, then focused on the interaction between ambient displays and users. The main purpose was to examine the general user attention towards ambient displays as well as the influence of different display designs. The study combined non-intrusive evaluation techniques as a quantitative approach to measure user attention with qualitative measurement of user perception and comprehension. The hypothesis was that variations in the display design affect the user attention towards the display. As additional evidence knowledge transfer was incorporated assuming that a better knowledge transfer is another indicator for an effective attention design. The criteria of interest were noticeability, disruption, comprehension, appeal, and relevance. The assumption was that these criteria have a direct influence on the knowledge transferred.

The presented results showed a high degree of user interest in the displays over time. The highest attention rate was measured during the first days of the study, while it peaked again in the middle and at the end of the study. The user interest did not stabilise in the course of the study calling for a longer evaluation period. The results were inconclusive regarding the initial hypothesis on the effectiveness of the chosen representational fidelity and the level of notification. However, the results suggested that the chances are higher to get the user attention when designing ambient displays with easy to grasp information and a sensible but not demanding level of notification.

Besides looking at the quantitative attention data the study tried to support it's claims with additional qualitative data. Supporting the conclusions drawn from the actual attention measurement, the reported results were inconclusive regarding the reported disruptiveness and comprehension of the displays. Participants took more notice of an interruptive display presenting symbolic information. At the same time they also felt more disrupted by it. These factors influenced each other. The study results also revealed other potential relationships, especially the high impact of an appealing information visualisation. The presented information was perceived more useful and relevant, while the information display was considered less disruptive. The noticeability of the display improved the comprehension of the information presented.

Following the initial hypothesis, this should have also affected the knowledge transferred and thus provided another indicator regarding the user attention. Again the results were inconclusive regarding the effectiveness of the chosen representational fidelity and level of notification. Nevertheless they provided evidence for the importance of providing comprehensible and relevant information. Thereby the perceived usefulness and relevance of the presented information acted as a trigger for the knowledge transfer. The result called for a contextualisation of the information presented.

Finally, the second empirical study into the research and development of ambient learning displays was presented in **Chapter 10**. The study reported an intervention to investigate previously identified research challenges on the evaluation and use of ambient displays in a learning context with the objective to gain insights into the interplay between display design, user attention, and knowledge acquisition. A display prototype corresponding to the main ambient display characteristics was designed, applied in a controlled authentic setting, and evaluated accordingly. The prototype conveyed indexical information and was enhanced with a custom-built sensor to measure user attention and trigger interruptive notifications. Using an experimental research design, a treatment group exposed to this attention-aware display design was compared to a control group.

The research questions were whether the attention-aware display design could:

- capture the user's focus of attention,
- influence the knowledge gain, and
- meet the general ambient display requirements.

The first hypothesis stated that an attention-aware display design attracts the attention earlier and retains the attention longer. The results showed clear evidence to support this hypothesis. The group exposed to the attention-aware display design reached the second attention level significantly earlier than the control group, on average in almost half of the time. The attention was also retained longer in the treatment group. The participants paid significantly more attention than the control group, on average more than twice as much.

The hypotheses regarding the second research question were that there is a correlation between user attention and knowledge gain in general and that an attention-aware display design can facilitate this gain. The results showed evidence to support both hypotheses. There was a positive relation between the amount of attention a participant paid towards the display and the participant's score in the knowledge test. Overall when participants paid more attention, their knowledge test scores were higher. Even taking prior knowledge into account the group exposed to the attention-aware display design still scored significantly higher than the control group. Overall the attention-aware designed display using indexical representation and interruptive notifications attracted and retained attention in such a way that the acquisition of knowledge (i.e. the comprehension of the presented information) was effectively facilitated.

The last hypothesis then stated that there would be no difference in meeting the general ambient display requirements caused by the design. The results only partly showed evidence to support this. The group exposed to the attention-aware design rated the display significantly more distracting than the control group. When it comes to the perceived mental effort required for filling in the questionnaire while paying attention to the display, no significant difference between the groups was found. This lack of significance supported again the hypothesis. The hypothesis was further supported when examining the number of shifts between the periphery and the focus of attention. Due to the notifications the treatment group shifted more but the difference between the groups was not significant.

Limitations of this research

Several factors limited the conducted research and development of ambient learning displays, i.e. the ability to answer the research questions effectively, achieve the research objectives, or provide evidence for hypotheses. These factors can be structured into design limitations and limitations related to evaluation. Overall the chosen application domain has of course a major impact on the learning conditions in general and the design and evaluation of respective ambient learning displays specifically. Authentic and situated learning usually occurs when learners are strongly related to the placement they are active in and at the same time far away from traditional (mostly formal) learning capabilities they would usually make use of. The characteristics of the current placement and the requirements of the learners have an influence on the assumptions the learners may have, the conditions they may find in situ, as well as technical constraints of the settings.

In terms of design limitations, one issue is the importance and influence of an aesthetically pleasing design especially when heading for an end-user product. The emphasis on aesthetics is one of the design dimensions derived from the taxonomy of ambient information systems by Pousman and Stasko (2006). This dimension was mostly ignored throughout the conducted research. The reason for that was the focus on evaluating the effects of ambient information presentation on learning and learning support rather than actually developing end-user products. In the context of this research putting too much emphasis on aesthetic display design was not feasible, but needs to be considered when applying the outcomes into practice.

More limitations regarding the design can also be identified in relation to the other design dimensions (i.e. information capacity, representational fidelity, and notification level). The information presented by the developed prototypes was mainly limited to factual knowledge with some implications for the evaluation, which did not go beyond the simple recall of the acquired information. Addressing also the conceptual or procedural knowledge dimensions and/or more complex cognitive process dimensions should improve this. As described within the presented conceptual framework, the revised taxonomy of educational objectives by Anderson and Krathwohl (2001) describes and relates these dimensions. The second empirical study was a first step in this direction. Furthermore, it can be argued that the interruptive notification design used in the empirical studies was too obtrusive (even distracting) and that the observed effects are merely a result of this. Of course, the prototypes were designed in such a way that their experimental variations depicted borderline manifestations of the manipulated ambient display characteristics. Reproducing the observed effects, future designs should gradually decrease the level and frequency of notification. However, finding the right balance between obtrusiveness, appeal, and effectiveness remains one of the biggest design challenges. The reported results can only provide rough design guidelines that need to be reconsidered in any given context.

Within the empirical studies, limitations regarding the measurement and analysis of user attention towards ambient displays were revealed. In the first empirical study the quantitative approach using sensor data was no reliable measurement of user attention. Single users could not be identified and thus no statistical methods were applied for the analysis. The data only presented a rough estimation of the actual user attention. The added qualitative approach did not solve this problem completely. The gathered questionnaire data was not a valid measurement of user attention. Single users could be identified and thus statistical methods were applied to analyse the data. Still the used questionnaire was no conclusive inventory of user attention. Nevertheless the combination of quantitative and qualitative measurement provided already a more holistic view on user attention. In the second empirical study the effects of these limitations were reduced. Again sensor data was used as a measurement of user attention, but the experimental setting allowed identifying single users. Further improvements of the custom-built attention sensor and more detailed logging capabilities made the measurement reliable and allowed detailed statistical analysis. Another limitation is also related to this measurement. The user attention was measured conceptually assuming that a user pays attention to the display and the information presented whenever looking at it. Using the custom-built attention sensor this process is even more abstracted to a level where facing the display frontally equals looking at the display and thus paying attention. Although this broad abstraction is confirmed by previous and related research, there are much more reliable measures available. A proposed solution was eye tracking. Even though eye tracking becomes less intrusive with latest technical developments (e.g., mountable remote trackers, tracking glasses), it is still more intrusive compared to the sensor method used in the empirical studies.

Finally, the evaluation of ambient learning displays in the conducted empirical studies has also several limitations. The main issue is related to the experimental setting used. As noted in the theoretical foundations, the evaluation of ubiquitous scenarios in laboratory settings is self-contradictory. While ubiquitous computing and the derived ubiquitous learning scenarios are characterised by the “anywhere, anytime” paradigm, laboratory settings per se exclude these features as they postulate the full control of all confounding variables. Evaluation techniques need to take into account the current context, environment, and conditions the user is experiencing within the situation that is observed. Kaikkonen et al. (2005) also discussed this tension. While lab settings offer a context without the danger of uncontrollable external variables, they have also been criticised as having a very low ecological validity. On the other hand, field settings suffer from many external variables that can influence the results of an experiment while being highly authentic and therefore offering the best ecological validity possible. Thus for both presented empirical studies the core question was how to evaluate in realistic settings controlling confounding variables? The experimental setting used in the second empirical study proved to be a good compromise between internal validity and ecological validity.

Implications and future research

The presented vision of ambient learning displays highlighted the challenges and explored the possibilities that lie in the convergence of mobile and ubiquitous learning in combination with the utilisation of contextualised digital content as valuable resources to support learning. The empirical findings delivered new scientific insights into the authentic learning support in informal and non-formal learning situations. The project investigated if there is a measurable benefit utilising ambient information presentation for a contextualised learning support within ubiquitous learning environments. The presented results of the conducted research and development entail several practical implications especially when designing and evaluating ambient learning displays.

Examining existing prototypical ambient display designs in related research work revealed that for acquiring relevant contextual information the increasing amount of sensors available on a personal level and within the environment are exploited to monitor user activity and behaviour. The gathered information is then to a great extend channelled back harnessing the learners' sense of vision. Here the great potential of addressing multiple senses (especially in a learning context) is left unexploited. Important senses, such as hearing and haptic, are clearly underrepresented across the reviewed prototypes and require deeper investigation. Inspecting the use of ambient displays for learning revealed that the majority of prototypes address learning only implicitly by raising, enhancing, or supporting awareness, changing behaviour, giving feedback, providing assistance and guidance, or just by presenting information. More effort needs to be put into research addressing learning explicitly. In terms of framing into the learning process, prototypes designed and developed with explicit learning purpose need to go beyond the factual knowledge dimension addressing solely lower cognitive processes. Beside that, effective means to evaluate learning need to be identified and applied. This is one of the crucial aspects towards ambient learning displays. To go beyond the mere goal to support awareness and lay the foundation for learning processes supported by ambient displays, more effort needs to be put into research on concepts like persuasion, motivation, feedback, and behaviour change.

The mapping of existing prototypes with the introduced classification framework led to first general design implications, taking into account the instructional characteristics considering concepts like situational awareness and feedback. The reviewed ambient display prototypes could be described with and classified within the used taxonomy. This illustrates that the taxonomy is already well elaborated and does meet the requirements of an integrated framework for ambient learning displays. Although the framework as it is proved to be suitable to draw conclusions on the effectiveness of prototypical variations in a learning context, several research gaps and shortcomings have been revealed. Especially the impact of a direct interaction on learning and the motivation to learn has not been investigated. Also, the relation to the cognitive processes of learning and the role of changing interaction modalities accordingly lacks in-depth research. Connected to that but more an instructional question is the underutilisation of the displays' ability to move between the users' periphery and focus of attention, as most prototypical designs stay within one or the other. It is also questionable if the type of instructional feedback specified is sufficient to cope with the changed handling of information and interaction modalities offered by pervasive technologies such as ambient displays. Other types of feedback might be more efficient. The effect of location-based or contextualised feedback is a yet unexplored research direction in the feedback literature for which ambient learning displays can play an important role in the future. The contextualisation component is not mapped and explored sufficiently within the framework, although the correlation of context, display effectiveness, and chosen design is obvious.

The empirical findings helped to understand and estimate the potential of the introduced ambient learning display prototypes. The studies focusing on user attention revealed that the effectiveness of ambient displays highly depends on surrounding conditions, e.g. differences in the frequency of users passing-by during the day. Existing daily routines need to be considered and the display design should be adapted accordingly. Several guidelines for an effective attention-aware display design can be derived. Successful display designs need to be contextualised and should not go beyond ‘just the right’ level of obtrusiveness while providing glanceable information. A possible bias is the novelty effect that accounts for outstanding user attention shortly after deployment and then levels off quickly. To reach the next phase and finally get the desired message through, users need to be intrigued and motivated. The intended transfer of knowledge is initiated when the presented information is both relevant and appealing. Finally, comprehensibility facilitates the process. This also confirms for instance McCrickard et al. (2003a) stating that the main challenge for an effective ambient display design is the right balance of attention and usability. How to deal with this trade-off is mainly influenced by the intended use of the display. Future research will then focus on the coherent attention-aware and contextual design of ambient displays.

In terms of the observed effects, the approaches offered a promising way to increase awareness, initiate behaviour change, and support knowledge acquisition. Learning was addressed explicitly. Although the variation on the prototypes’ representational fidelity and notification level proved to be inconclusive in the first study, the results revealed different effective design strategies depending on the purpose of the educational initiative. To form habits the results called for a provision of (direct) feedback reflecting individual behaviour and the use of alternative motivational designs, such as gamification (Werbach and Hunter, 2012). It became clear that confounding variables need to be somehow controlled and generalisability reduced to reach the desired goal and evaluate learning effectively. Consequently, in the second study the main purpose was then to design a noticeable, unobtrusive, and comprehensive display that is capable to retain user interest over time, evaluate this design in an authentic setting controlling confounding variables, and gain insights into the interplay between display design, user attention, and knowledge acquisition. The attention-aware display design attracted and retained user attention more effectively and significantly facilitated the acquisition of knowledge. The design was evaluated in an authentic setting using valid methods. Considerably more work will need to be done to determine the cognitive transfer of knowledge on the long term. Furthermore, the sustainability of the observed attention effect needs to be investigated in detail.

Towards ambient learning displays still some work needs to be done, wherein this thesis can be taken as basis and inspiration to go beyond. The focus needs to be on the development of new display types addressing the whole range of senses as well as the utilisation of existing already embedded displays. Regarding learning scenarios theoretical concepts like situational awareness and feedback need to be incorporated to shape learning experiences so far not touched upon by ambient displays. The actual design of ambient learning displays in compliance with ambient display characteristics remains challenging but not impossible.

Designing an ambient learning display

Based on the results of this thesis an ambient learning display can be designed in the following way. Certainly, the display design follows the original definition of ambient displays, but slightly breaks with certain aspects to find the right balance between unobtrusiveness, appeal, and effectiveness within the learning context. In addition to whatever is happening in the learner's main focus of attention the embedded display enriches the environment with digital information using an appealing representation. This information needs to be contextualised, comprehensible, and relevant. To raise the learner's awareness of something, the display makes use of an interruptive design showing easy to grasp and glanceable information. To address higher cognitive process dimensions, such as knowledge acquisition and transfer, the display presents rather abstract information and makes use of a less interruptive design. This process can be facilitated with at least a simple verification feedback on the performance or behaviour of the learner and the correction of possible errors. In the long term the display needs to provide elaborated feedback or use an appropriate incentive mechanism to engage and motivate the learner further and not loose the learner's interest and attention. In general the display follows the basic rationale that the more attention a learner pays, the more knowledge can be transferred. Therefore, the learner attention needs to be balanced in a way that the noticeability and disruption of the display are adjusted to the targeted comprehension and relevance. This can be done with a careful attention-aware design involving the display, the learner, and the environment. Such a design then also enables the continuous non-intrusive evaluation of the various aspects, which can again be used to create a closed feedback loop.

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Summary[4]

This thesis presented the results of the conducted research and development of ambient learning displays. The reported results are structured into three parts: theoretical foundations, formative studies, and empirical findings. An elaborated conceptual framework and an extensive literature review were used to explore the research field and lay the foundation for further research. **Chapter 1** outlined the vision of ambient learning displays – enabling learners to view, access, and interact with contextualised digital content presented in an ambient way. This vision was based on a detailed exploration of the characteristics of ubiquitous learning and a deduction of informational, interactional, and instructional aspects to focus on. To provide a theoretical foundation for the following research, relevant research findings, models, design dimensions, and taxonomies were examined. The result was a conceptual framework that defined ambient learning displays. The framework consists of parts dedicated to user and context data acquisition, channelling of information, and delivery of contextualised information framed in a learning process.

The first part of the conducted literature review, presented in **Chapter 2**, depicted characteristics, classified prototypical designs, and shed light on the actual use of the covered ambient displays, their application context and addressed domains as well as the type of studies conducted, including the used methodologies and evaluation approaches to measure their effectiveness and impact. The results showed that the acquisition and delivery of information through ambient displays were in line with the presented conceptual framework. The means to channel the information and the framing into a learning process needed further investigation. The literature review continued in **Chapter 3**. This second part focused on the actual use of ambient displays in a learning context. The goal was to assess ambient displays with an explicit or implicit learning purpose and the classification of respective prototypes on the basis of an extended classification framework, including the informational and interactional design of the prototypes, research objectives and results of the reported empirical studies, as well as deducible instructional characteristics. The

[4] This chapter incorporates abstracts, discussions, and conclusions from several publications.

results exposed that the explicit use of ambient displays for learning was not a prominent research topic, although implicitly ambient displays were already used to support learning activities fostering situational awareness by exploiting feedback. The mapping of the corresponding prototypes with the introduced classification framework led to first general design implications, taking into account instructional characteristics.

Several formative studies informed the theoretical work as well as the design and development from different perspectives. **Chapter 4** described an explorative study conducted to inform the research of ambient learning displays. By asking domain experts the used concept mapping approach identified the major educational problems that can be addressed by mobile learning and clustered these problems into domain concepts that contribute to a definition of mobile learning. The main domain concepts identified were “access to learning” and “contextual learning”. This reflected the claim on mobile learning to enable learning across context, facilitating and exploiting the mobility of the learners. Although the study targeted on the mobile learning domain, the results were in a broader view also considered valuable for the ubiquitous learning domain and thus for the conducted research.

The results of two projects that informed the design and development of ambient learning displays were presented. The first project, presented in **Chapter 5**, elaborated and developed an infrastructure that supports energy conservation at the workplace. The purpose was to make energy consumption data visible and accessible to employees by providing dynamic situated consumption feedback. The presented results showed the general interest in the topic and indicated the effectiveness of the introduced means towards the conservation of energy. The second project, presented in **Chapter 6**, implemented a pervasive game to increase the environmental awareness and pro-environmental behaviour at the workplace. In relation to the previous project the purpose was to go beyond increasing awareness and providing personalised information and instead focus on the potential of a pervasive game to increase knowledge, pro-environmental consciousness, and last but not least change consumption behaviour. The results showed that incentive mechanisms are less important than challenging game components that involve employees in proposing solutions for energy conservation at the workplace.

Chapter 7 then described a lecture series that summarised the theoretical foundations. Furthermore the chapter reported on a participatory design study conducted in the course of the lectures with the goal to inform and ease the design process of ambient displays for learning. The presented results showed a variety of usable ambient display types, possible learning scenarios, and specific design proposals towards ambient learning displays.

Following up the theoretical work and the formative studies, respective ambient learning display prototypes were then evaluated in empirical studies. The first empirical study into the research and development of ambient learning displays was presented in **Chapter 8**. The first part of the study reported an intervention to initiate environmental learning and facilitate pro-environmental behaviour. The purpose was to examine the impact of ambient learning displays on energy consumption and conservation at the workplace, more specifically the evaluation of learning outcome and behaviour change. The results did not provide clear evidence that the design of the displays influences the learning outcome or that the displays lead to pro-environmental behaviour change. Nevertheless the sole deployment of the display prototypes eased the comprehension of the information provided and lowered the need for additional information. Furthermore, the results provided insights and revealed several challenges for future research. The second part of the study, presented in **Chapter 9**, then focused on the interaction between ambient displays and users. The main purpose was to examine the general user attention towards ambient displays as well as the influence of different display designs. The study combined non-intrusive evaluation techniques as a quantitative approach to measure user attention with qualitative measurement of user perception and comprehension. The results showed a high degree of user interest in the displays over time, but did not provide clear evidence that the design of the displays influences the user attention. Nevertheless the combination of quantitative and qualitative measurement provided a more holistic view on user attention. Several guidelines for an effective attention-aware display design were derived.

Finally, the second empirical study into the research and development of ambient learning displays was presented in **Chapter 10**. The study reported an intervention to investigate previously identified research challenges on the evaluation and use of ambient displays in a learning context with the objective to gain insights into the interplay between display design, user attention, and knowledge acquisition. The results provided evidence that an attention-aware display design attracts and retains user attention more effectively and that there is a positive relation between knowledge gain and user attention. Furthermore, the design significantly facilitated the acquisition of knowledge.

The thesis concluded with a **General Discussion** reviewing all reported results and their practical implications, general limitations of the conducted research, as well as future research perspectives. Overall the conducted research and development revealed that ambient displays could be designed and implemented to fulfil a given purpose successfully, possibly also for learning. Once implemented the known long-term effects as well as the contextual factors that influence the display's efficiency need further investigation. In the dawning age of ubiquitous computing,

ambient displays represent a technological concept with great potential for learning. The presented vision of ambient learning displays highlighted the challenges and explored the possibilities that lie in the convergence of mobile and ubiquitous learning in combination with the utilisation of contextualised digital content as valuable resources to support learning. The empirical findings delivered new scientific insights into the authentic learning support in informal and non- formal learning situations. The conducted research was mainly limited regarding the chosen application domains, the prototypical ambient display designs, and the occurring tensions when evaluating between lab and field settings. Towards ambient learning displays still some work needs to be done, wherein this thesis can be taken as basis and inspiration to go beyond.