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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" (**?**). 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 (**?**). 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" (**?**). 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" (**?**). Inspired by Weiser's vision, **?** introduced ambient displays in

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

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 **?** 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

Mobile authoring of OER 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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0.1 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 Bloch et al. (1994). 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 Hummel (1993), Tripp (1993). Rule Rule (2006) 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 Herrington and Oliver (2000) 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 Specht and Kravcik (2006). Lombardi and Oblinger Lombardi (2007) 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 Zimmermann et al. (2005) and recording real-life experiences Barreau et al. (2007), Hodges et al. (2006) 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 Jesse (2013) 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.

0.2 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 Pérez-Sanagustín et al. (2012), Grüntjens et al. (2013), Sampson and Zervas (2012), Gicquel and Lenne (2011), Mathews (2010), MartIn and Carro (2009), Cabada et al. (2009), Kim et al. (2013). 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 Amiel (2013) concludes that remixing learning resources is still not mainstream in education. Collis and Strikjer Collis and Strijker (2003) 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 Mugwanya and Marsden (2010) 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 Pérez-Sanagustín et al. (2012), Grüntjens et al. (2013), Sampson and Zervas (2012), Gicquel and Lenne (2011), Mathews (2010), MartIn and Carro (2009), Cabada et al. (2009), Kim et al. (2013) 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 Wagner (2002), Duval and Hodgins (2003). 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.

0.2.1 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 1.1 The 24 resulting articles were fully analyzed and desktop-based authoring

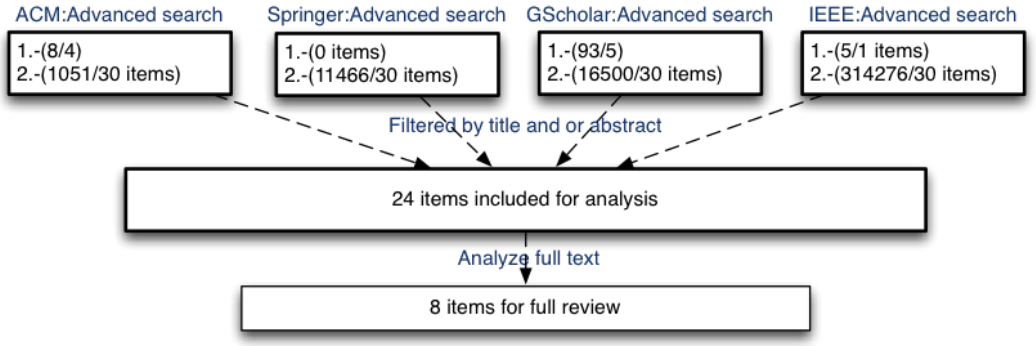


Figure 1: Mobile authoring tools review procedure

tools were discarded. This review has resulted in eight authentic mobile authoring environments listed in the appendix 1 "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 Duval and Hodgins (2003). The result of this comparison is synthesized in table 1. Resources that have a low 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

Table 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)	-	-

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 Rensing et al. (2005) 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 Tabuenca et al. (2012a). 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 Amiel (2013) 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 2) 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* .

0.3 Design of the Mobile Authoring Tool for AR-Learn

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.

Table 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	

0.3.1 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 Duval and Hodgins (2003). 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. Schmitz et al. (2013) 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).

- The Mindergie games have been designed and tested at a university campus in the context of an energy conservation pilot Börner et al. (2013b). 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.

(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 2: Training cardiopulmonary resuscitation in schools with ARLearn Schmitz et al. (2013).

- In collaboration with the United Nations Refugee Agency Ternier et al. (2012a), 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[2] 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* .

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

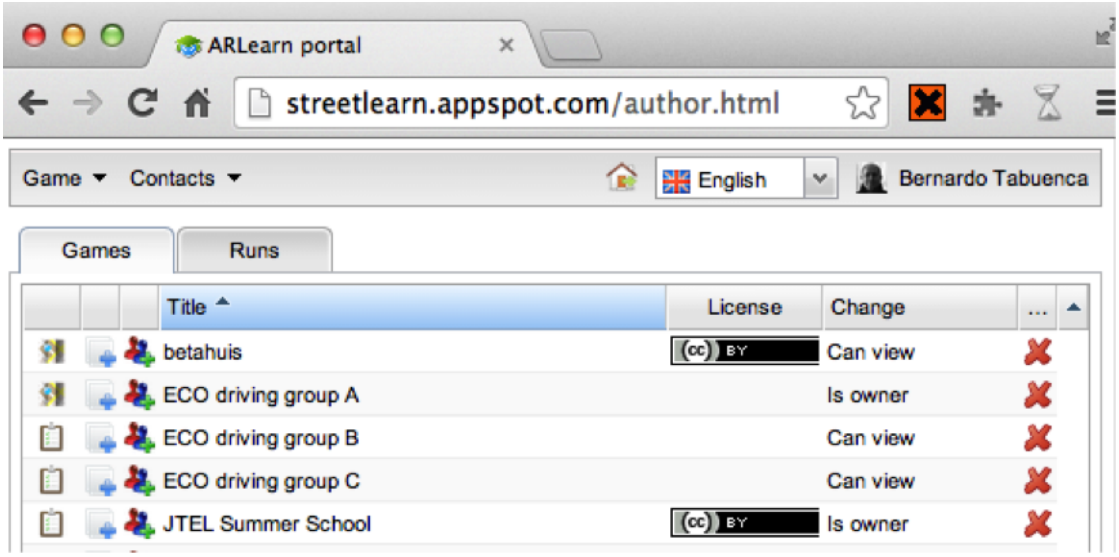


Figure 3: Desktop authoring environment in ARLearn

0.3.2 *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 real world artefacts with game content. *MAT for ARLearn* has been designed starting a "Mobile Authoring" branch [3] from the last release of the open source code available for the ARLearn mobile[4] 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 2.

The *MAT for ARLearn* features three main approaches to foster ubiquitous and universal access to educational resources: 1) an author can create and contextualize

[3] *MAT for ARLearn* source code. https://code.google.com/p/arlearn/source/browse/?name=MobileAuthoring
[4] ARLearn in Google Play. https://play.google.com/store/apps/details?id=org.celstec.arlearn2.android

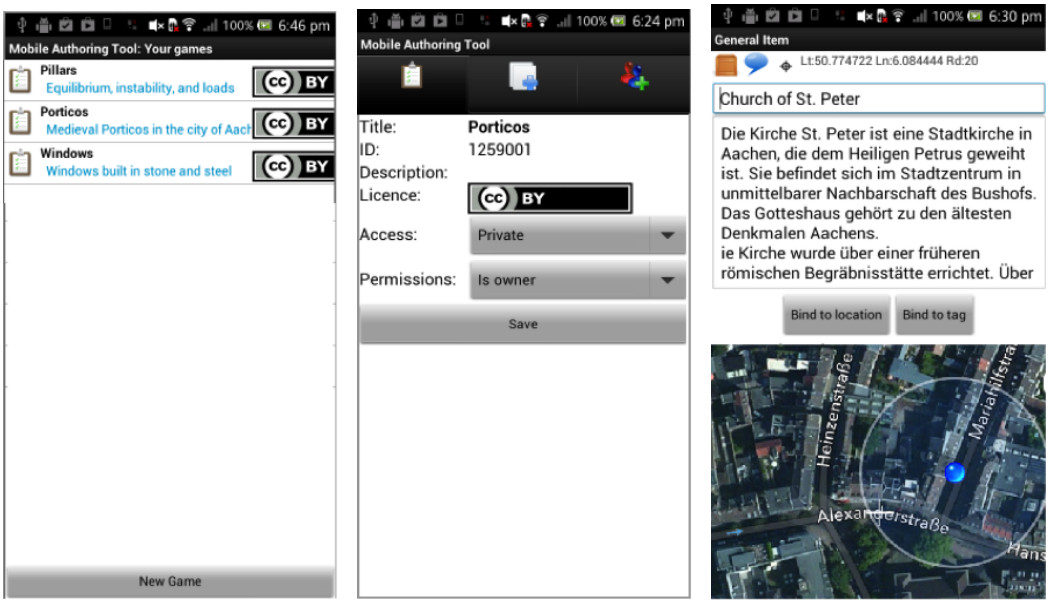
new content; 2) an existing game (or an item) can be recontextualized to a new environment; 3) licensing selection is supported to promote the reuse, revision, remixing, and, redistribution of educational materials as open educational resources (OER).

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.

0.3.3 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



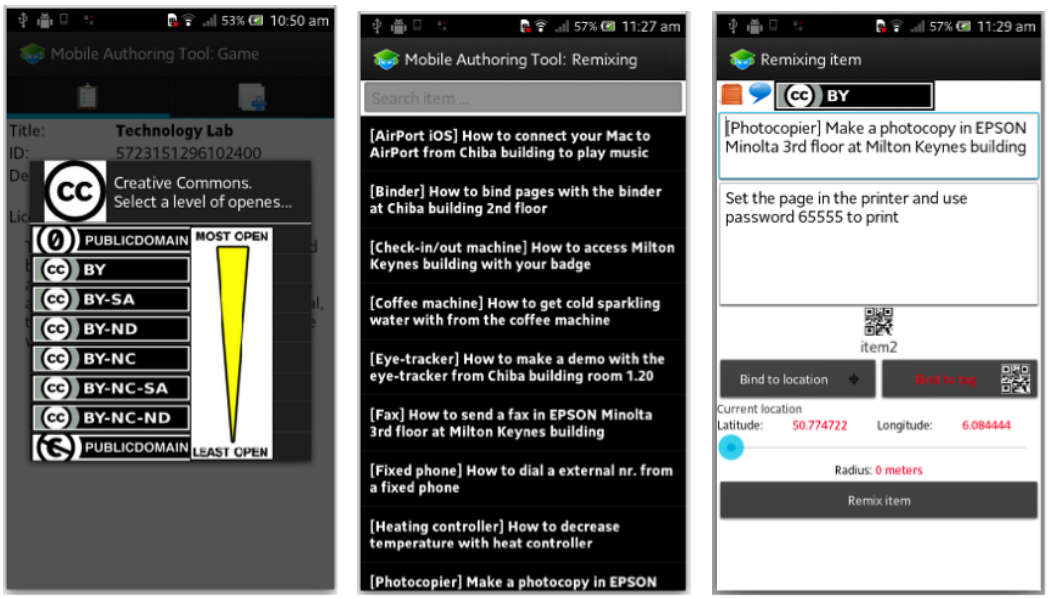
(a) "My games" screen lists games created by the author **(b)** Authoring games screen **(c)** Contextualization of educational resources

Figure 4: Mobile Authoring Tool for ARLearn interface

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 Vollmer (2013). 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.

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-



(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 5: Remixing and recontextualizing items with the *MAT for ARLearn*

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.

0.3.4 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 Atkins et al. (2007). 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.

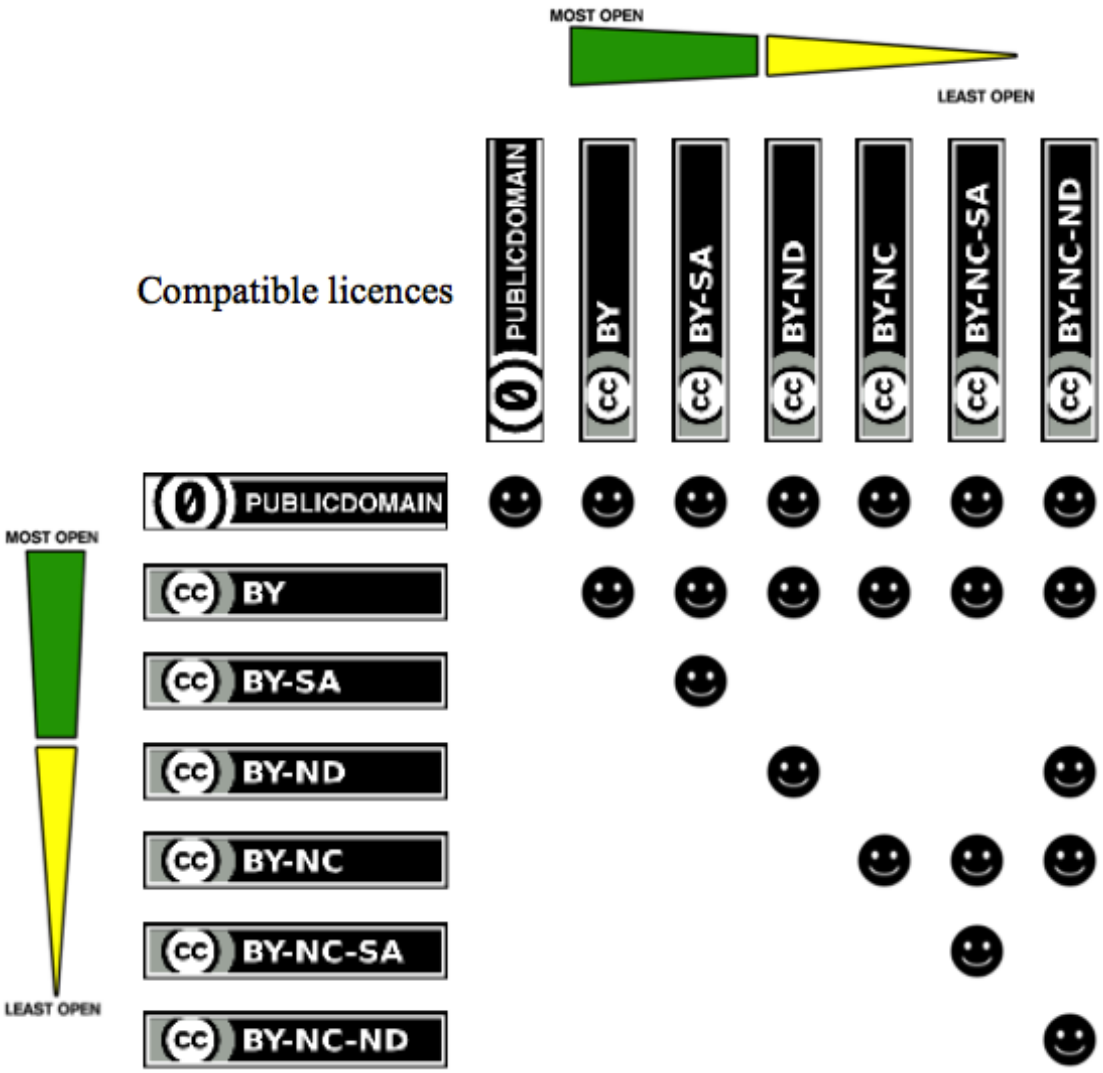


Figure 6: Remix compatibility according to spectrum of freedom in Creative Commons licenses Vollmer (2013).

0.4 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.

0.4.1 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.

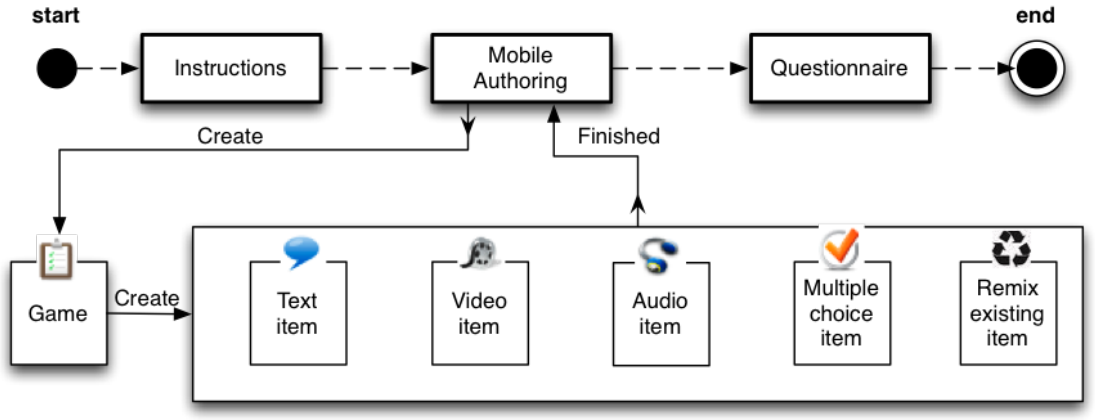


Figure 7: Flow of the experiment. UML-State diagram

0.4.2 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 Brooke (1996). 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 Sauro (2011) 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” Hassenzahl (2001) 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 Benedek and Miner (2002). These product reaction cards have been transferred to a digital version and published as Reactiondeck toolkit Storm (2012). 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

Figure 8: Evaluation of hedonic quality with the Reactiondeck Storm (2012).

an open text box why did they selected that card.

0.5 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.

0.5.1 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

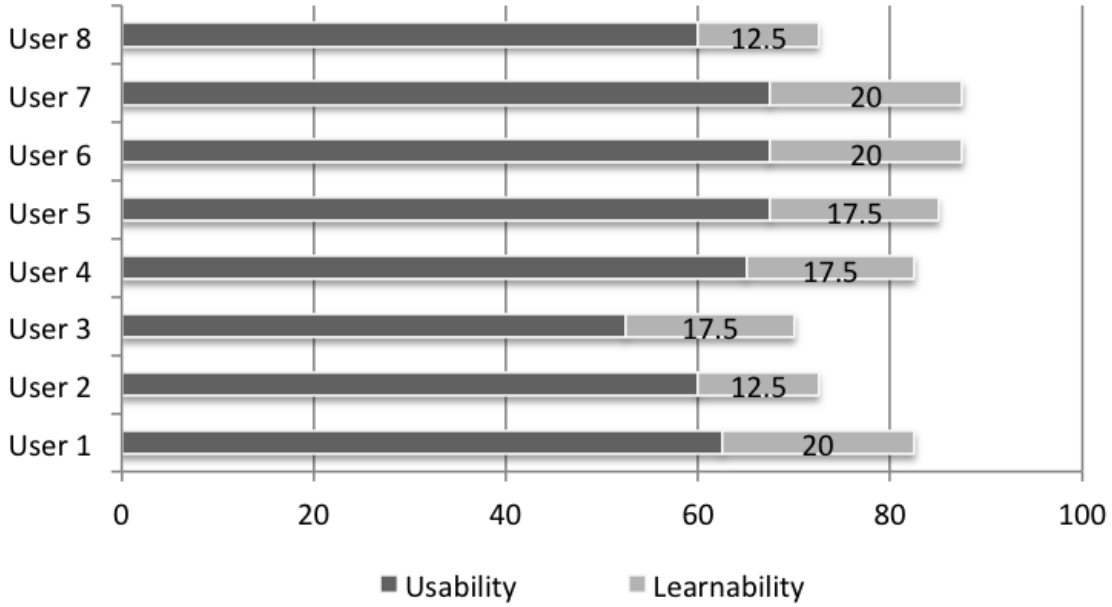


Figure 9: Evaluation of Usability and Learnability with the System Usability Scale (SUS) Brooke (1996).

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).

0.5.2 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".

Figure 10: Tag cloud visualization for the measure of hedonic quality.

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 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".

0.6 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 Duval and Hodgins (2003) (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 2).

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 Virvou and Alepis (2005) 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 Specht and Kravcik (2006) 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 Bonsignore et al. (2013) 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*) Kim et al. (2012) 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*), Jesse and Chang (2012) 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 Giemza et al. (2012) 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 Wu et al. (2006) 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 Multisilta et al. (2010) 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 limitations 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 11: Mobile authoring tools classification according to features.

Part II

Stop and Think: Exploring Mobile Notifications to Foster Reflective Practice on Meta-Learning

Chapter 1

Stop and Think: Exploring Mobile Notifications to Foster Reflective Practice on Meta-Learning

Nowadays, smartphone users are constantly receiving notifications from applications that provide feedback, as reminders, recommendations or announcements. Nevertheless, there is little research on the effects of mobile notifications to foster meta-learning. This paper explores the effectiveness of mobile notifications to foster reflection on meta-learning by presenting the results of two studies: 1) a formative study with 37 secondary school students offering a daily reflection and reporting exercise about their learning experience during the day; 2) an experiment involving 60 adults to read an eBook on energy-efficient driving for one hour. During that time, the participants received mobile notifications inviting them to reflect in-action. On the one hand, the results from the first study show that students do not have a habit of seeing themselves as learners and developing a *"professional"*awareness about their daily activity at work/school. On the other hand, the second study explores the effects of different notification types on knowledge gain and motivation. Results envision a higher knowledge gain and motivation for the group assigned with the least complex interactions with mobile devices during the reflection exercise. Finally, these results are discussed and important research questions for future research on mobile notifications are raised.

Chapter 1. Stop and Think: Exploring Mobile Notifications to Foster Reflective Practice on Meta-Learning

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1.1 Introduction

Based on current trends Publishing (2011), it is estimated that 84 percent of today's young people in OECD countries will complete upper secondary education over their lifetimes. This period consolidates students' basic skills and knowledge towards a successful transition to either an academic or a vocational pathway. While graduation rates give an indication of the extent to which education systems are succeeding in preparing students to meet the labour market's minimum requirements, they do not capture how the students have developed an identity as learners. The acquisition of such an identity, and the associated reflective transversal skills, grow in importance in a *"lifelong learning society"*European Comission (2005). In the formal education system it is a challenge to find ways to provide students with opportunities to mentally evoke what they have learned throughout the day, so that this experience can be turned into a deliberate object of attention and reflection.

*"Learning to learn"*and *"Digital competence"*are highlighted as two of the eight key competences for lifelong learning in the European Reference Framework European Commission (2007). The proliferation of wirelessly-networked technologies facilitates the scaffolding of *"seamless learning spaces"*Chan et al. (2006) as an approach for continuing learning experiences across different scenarios, and emerging from the availability of one device or more per person. Biggs (1985) defines meta-learning as an awareness and understanding of the phenomenon of learning itself as opposed to subject knowledge. Hereby we conceive meta-learning activities as the increase of knowledge and motivation on learning when triggered by introspective episodes of reflection on user's own learning. Hence the present manuscript explores different instantiations of notifications received on mobile devices with the aim to foster reflective practice for meta-learning measuring the variations in dependent variables of knowledge and intrinsicmotivation.

Reflection is the practice to become aware of an implicit knowledge base and to learn from experience Schön (1983). Schön coined the terms *"reflection in-action"*as the reflective practice performed while doing an activity to optimize the immediately following action, and, *"reflection on-action"*as the reflective practice performed when the activity has finished in order to review, analyse, and evaluate the situation and gain insight for improved practice in the future.

Previous work on reflection amplifiers in-action suggests that regular changes between meta-cognitive and content focus lead to more awareness and self-regulative competences in the learning process Bannert et al. (2009); Verpoorten (2012). Reflection amplifiers are compact and well-considered prompting approaches that offer learners structured opportunities to examine and evaluate their own learning Verpoorten et al. (2009). They are present as structured and repeated introspective

episodes, offered in the course of action and meant to make learning visible. The effectiveness of mobile notifications to foster reflective practice on learning (reflection on-action) has not been explored yet. Recent research suggests that mobile notifications by students produce distracting effects Fried (2008); Kraushaar and Novak (2010). Nonetheless, notifications received on mobile devices have also resulted in a positive impact, suggesting that the intervention is able to improve students' self-regulated learning effort. The study from Goh et al. (2012) used persuasive SMS interventions on undergraduate students for 12 weeks, showing that students who received SMS intervention performed better than students who did not receive SMS intervention. Cavus and Ibrahim (2009) investigated the effects in knowledge and enjoyment of sending SMSs with English vocabulary to 45 first-year undergraduate students concluding that students enjoyed and learned new words with the help of their mobile phones. Similar, Thornton and Houser (2005) used more elaborated notifications in the form of emails to teach English vocabulary lessons to university students concluding that students that received the mobile email learned more than those that received web-based email. Uzunboylu et al. (2009) implemented multimedia messages to increase awareness on environmental concerns. Measures of enjoyment, knowledge or awareness have been the focus of previous research.

This manuscript presents two studies evaluating approaches to stimulate learners' capacity of reflection by making *"what they learn"*a deliberate object of attention Watkins (2001). The research is embedded into a larger project focusing on mobile support for lifelong learning Tabuenca et al. (2013, 2014a,d). More specifically, in this work we have focused on the use of notifications instantiated in mobile devices for lifelong learning support. Research on notification and prompting for reflection suggest different strategies for reflection on-action and in-action. This work advances the research on mobile notifications and reflective practice presenting two studies:

- A formative study aimed to reflect on-action. This study was carried out during two school days and two days off, where 37 college pupils were prompted via mobile SMS notification for a daily reflection and reporting exercise about how they have learned during the day (intensity and channels).

- An experimental study aimed to reflect in-action. In this study, 60 university employees were invited to read an eBook on energy-efficient driving. During that time, they were prompted via mobile notifications to reflect and report on what they had learned.

The following sections introduce both experiments by mapping the goal of the research to existing gaps that need to be covered. The results are discussed and

important research questions are raised.

I How to design mobile notifications for student reflection support

The first study presented in this manuscript transposes the concept of *"Reflection amplifiers"*Verpoorten et al. (2009) to mobile (meta-)learning, after-school setting and analytical scrutiny onto one's learning day. In this study, students have been assigned to reflect about the learning affordances offered to them throughout the day. Three main research questions have guided this formative study:

1. How will students respond to invitations to reflect on personal learning sent on their own device and outside the school hours (participation)?
2. What insight does this sampling of experience bring regarding how learning takes place in students' today common life (channels of learning and perceived intensity)?
3. What effects of these structured episodes of introspective reflection can be pinpointed on dimensions of learning (familiarity, appreciation, perceived learning, account of the learning experience)?

In a second experiment, variations of mobile notifications prompting users to reflect in-action have been explored, and the effects on knowledge gain and motivation have been quantified. On the one hand, thinking aloud Nielsen et al. (2002) and sampling of experiences Hektner et al. (2007) have been pinpointed as effective approaches to foster reflective practice on learning. The majority of the studies sampling experiences with educational implications have involved children and adolescents Hektner et al. (2007). Hence, this experiment has been performed with adults. On the other hand, Wong and Looi (2011) identify ten seams by which learning experiences are disrupted and for which mobile seamless learning technology has to find new solutions. One of them is *"the combined use of multiple device types"*. In many cases it is presumed that learners interact only through a single channel or device. However, the technological framing can vary from single device interaction to the presence of multiple devices with different characteristics and capabilities that are used simultaneously. Likewise, the proliferation of tagged objects and the incorporation of tag readers (QR codes, NFC tags) to mobile devices are facilitating the exchange of educational content across devices. This experiment explores variations of mobile notifications for adults sent with the aim to foster reflective practice in-action while accomplishing a learning activity. This setup contemplates the combined use of multiple devices for learning and has been

guided on three main research questions:

4. How do students perceive asynchronous notifications in contrast to user-triggered notifications prompting reflection in-action, and, what effects on knowledge and motivation can be highlighted?
5. What insights can be gained when using mobile notifications prompting the student to actively externalize an exercise of reflection in-action, and, what effects on knowledge and motivation can be highlighted?
6. Which reflection cues are provoked by the spontaneous collection of learning objects with mobile devices, and, what effects on knowledge and motivation can be highlighted?

1.2 Study 1: Embedding reflection in everyday activity via SMS notifications

I Method

Participants

This study enrolled 37 college students (mean age = 17 years old, 37% female, 63% male). An iTunes voucher of 15 EUR rewarded their participation in the experiment. The voucher was delivered to students that completed both the pre-questionnaire and the post-questionnaire.

Materials

The formative study aimed to attract every student to perform the reflection exercise, no matter which mobile device they were using. It was decided to use SMSs notifications to make them all aware when the personal response system was ready to accomplish the reflection exercise. Participants that reported to own a phone with Internet connection (67%) could follow the link in the SMS (See figure 1.1a) to directly navigate within the personal response system. Participants without mobile Internet connection (33%) used alternative devices (personal computers or tablets) to log in via browser navigation of the same URL. The students' personal response system[1] selected for this formative study features multiple-choice questions

[1]Socrative. Multiplatform audience response system. http://www.socrative.com/

(figure 1.1bc), short text answers, and long text answers. This platform can be accessed from smartphones, tablets, laptops and personal computers. Materials, experimental design and partial results of this study were reported earlier (Tabuenca et al. (2012b)). The current paper provides additional data (Table 1.2 and dropouts examination) extending the analysis of these results and its implications.

Design

The design of this study considered the same treatment for all the participants. Regarding the independent variables, this formative study considered three measures:

- A pre-questionnaire gathered perception of students about the intensity of their learning week and the main channel they use for learning.
- A daily mobile questionnaire was the reflection amplifier of the study. It comprised one question about the perceived intensity of the learning day (figure 1.1c) and one question about the main channel of learning used during the day (figure 1.1b).
- A post-questionnaire left active during one week served to explore the effects of introspective episodes of reflection on meta-learning defined as awareness and understanding of the phenomenon of learning itself [5]. Hence, participants were prompted to reflect and report on *"What is learning?"*, their familiarity with reflective practice, their appreciation of the reflective practice, and their description of the learning experience. Additionally, they were asked to provide an account on their learning channels, and the intensity of their learning during the days of the experiment. The high rate of dropouts motivated the adaptation of a post-questionnaire with the intention to explore the reasons why some students did not take part in the daily reflective exercise.

Procedure

The study took place during an "experiment day" which offered students to discover the work of the Learning Innovation Lab (the authors' workplace) through the participation in empirical experiments. At the end of the day, a presentation provided an overview of mobile technologies for learning. Afterwards, the corresponding author introduced the participants to the exercise to be done in the next 4 days. The formative study was introduced to students as a reflection exercise in which they were supported to improve their awareness of their daily activity as learners. The famous speech of Steve Jobs at the end of the year session at

Figure 1.1: Formative study. Notifications fostering reflective practice on-action

Stanford University[2] was used as a stance on the importance to step back and consciously attend to one's own life and personal identity, here as a learner. The experiment required using both a SMS broadcasting system that would alert them about the reflection moment of the day, and a student response system where they should answer the questions they would be asked. The students completed the pre-questionnaire and a demo from both the SMS functionality and the student response system was performed.

The daily reflection exercise was performed during 4 consecutive days after the presentation of the experiment. This setup was designed to evenly distribute the reflection exercises across two days at school (Thursday to Friday) and two days out of school (Saturday to Sunday). It allowed to encompass the awareness and reflection on both formal and informal learning and to provide contrast to the descriptions of the learning experience. An SMS was sent to students every day at 8 pm alerting them that the student response system was ready to receive answers with their reflections. Students that had smartphone with Internet connection could click the link and perform the reflection exercise within the platform directly on their smartphone device. The virtual classroom enabled the teacher monitor how many students were performing the activity in real time. Finally, the students received an email inviting them to complete the post-questionnaire.

II Results

Participation

The first research question aimed to explore student's willingness to participate in a reflection exercise and to what extent students would react actively to regular invitations to reflect on personal learning experiences sent on their own device and outside the school hours. The decrease in participation (figure 1.2) was quite visible in each of the four iterations of the daily questionnaire (mean 2%), but was not as severe as the dropout rate from the pre-questionnaire to the mere entrance in the daily exercise (48%). The 29 recorded post-questionnaires comprised both the participative (56% [n=16]) and the dropouts (44% [n=13]). In this study, we refer to dropouts as the students that voluntarily decided not to take part in the daily reflection exercise (Day 1 to 4). Dropout students had the chance to get the reward (iTunes voucher) whenever they completed the post-questionnaire for dropouts.

Main invoked reasons for dropouts (n=13) were for 46% *"I did not receive any*

[2]Jobs, S. (2005). Commencement address delivered at Stanford University, June 12, 2005. Stanford Report. Available in http://www.youtube.com/watch?v=xoUfvIb-9U4

Figure 1.2: Evaluation of the participation in the formative study

Table 1.1: Channels of learning

Table here

*SMS"*and 38% *"I had no internet connection at that moment"*. No respondent selected lack of interest, boredom of the intrusive character of the experiment as justifications for not participation. The SMS monitor tool confirmed the failures delivering the messages: an average of 15% of the SMS were not delivered, a large majority thereof caused by a wrong phone number given by the students right from the start of the experiment. Additionally, the monitoring tool for teachers of the student response system displayed how many students were connected to the platform filling-out the questionnaire in every moment. From these observations, it can be concluded that the majority of the students reported their answers in the same moment they received the SMS.

Intensity of the learning day and channels used

The second research question aimed to gain insights on what this sampling of experience brings regarding how learning takes place in students' life focusing on their channels of learning (figure 1.1b). Table 1.1 summarizes the answers given by students both in the pre/post-questionnaires and in the daily reflection exercises. School and Internet were reported as the most important sources of learning.

The post-questionnaire shows that the majority of the participants in the daily reflective exercise reported the school as the main channel of learning during those days. Nevertheless, the majority of the dropouts identified Internet as the main leaning channel.

Episodes of introspective reflection

The third research question aimed to identify effects from these structured episodes of introspective reflection. The analysis of the reported answers supports pinpointing to the following four key aspects: *Familiarity with reflective practice* . Looking backward on one's life as a learner is not a deep-rooted habit of students if the answer to the question *"before the start of this experiment, can you remember the last time you thought about your learning day?"*is taken as an indicator. An 81% of the participants (n=16) answered *"No"*. *Appreciation of reflective practice* . Participants were asked whether they liked the reflection activity implemented through their smartphone. A 69% (n=16) answer positively. Four categories of answers emerged from the justifications of students valuing the experience:

- Gains in self-assessment (29%). E.g. participant #5: *"You look critically at what you have learned and how you might improve. Evaluating yourself adds to the learning experience itself"*.
- Gains in consciousness without further details (24%). E.g. participant #7: *"My interest steadily grew because it made me more conscious"*.
- Gains in meaning (18%). E.g. participant #18: *"It helps you realize that your day has much value. It is eventually about my life"*.
- Other answer (29%). E.g. participant #9: *"Very interesting and well done"*.

Only a few students gave reason for their dislike of the experiment: *"no learning comes from the reflection"*(participant #6), *"the reflection is quickly forgotten"*(participant #20), *"my reflection on learning takes place in the moment of learning and not afterwards"*(participant #21), *"I reflect on other things"*(participant #10), *"I've often asked myself before what I learned at school and often came to this conclusion: nothing"*(participant #2). *Perceived learning* . The answers to the question *"How intense was your learning day?"*were taken as indicator. This variable was measured with a 5-likert scale (figure 1.1c) where one indicated *"I have learned nothing"*and five indicated *"I have learned a lot"*. The pre-questionnaire prompted them to report how much they did learn during the on-going week, the daily questionnaire prompted them to report how much they did learn during that day, and the post-questionnaire prompted them to report how much they did learn during the days of the experiment. The post-questionnaire shows that perceived learning is higher when asked referring to the overall four days (3,6), than when asked individually in each of the days (ranged from 2 to 3). Dropouts reported 0,84 points less in perceived learning than the daily participants. *Description of the learning experience* . When students were asked to describe their learning experience during the week in the post-questionnaire, participants in the daily reflective exercise produced longer accounts in contrast to the ones that did not participated in the daily reflection exercise: 112 characters on average versus 88 for the non-participants. However, from a t-test, it turned out that these differences were not significant ($t(26) = 1.12$, $p = .26$, $d = 0.29$). The same conclusion was drawn from a chi-square test bearing upon the level of complexity of the accounts, assessed with a three-level coding rubric. Positive reports were normally longer than negative reports. These are some positive reports: *"It was an interesting experiment to become aware of what I learned. I found it a very useful experience to evaluate your own"*. *"I think it's a good experience because you look back at what you did, you discover things you could have done, or, things you need to do differently the next time"*. *"It was nice to think about what you learned, because you feel that you have at least learned something that you've done something. You*

Table 1.2: Perceived learning

Table here

become aware of the fact that you learn things at school". "Critically you look what you have done during the day and detect areas where you can improve". These are some negative reports: *"I found it nonsense".*; *"Not very useful".*

1.3 Study 2: Experimental study on reflection in-action with mobile notifications

While the first study provides some insights into how students appreciate the exercise of introspective episodes of reflection on learning instantiated on their own mobile devices, we have conducted a second study to explore whether these episodes of reflection can produce gains in knowledge and motivation. Hence, the purpose of the second experiment was to determine the relationship between the reaction produced by mobile notifications prompting the student to perform an exercise of reflection and a multidimensional measure of intrinsic motivation for adult lifelong learners. Likewise, a measure of knowledge is presented upon the variations in the type of mobile notification and, the type of reflection performed. Moreover, differences in the effect of harvesting multimedia learning-objects via mobile devices are explored.

Our assumption was that notifications aimed to reflect in-action result in a better knowledge and motivation if they are triggered when the user determines the best moment to do it (in contrast to automatic regular/random basis). Likewise, the authors assumed that the reflection accomplished both when collecting learning objects, and externalizing the reflection in an audio speech will result in a better outcome.

I Method

Participants

This experiment enrolled 60 employees (mean age 45) from the Open University of The Netherlands invited to voluntarily participate in an experiment on energy-efficient driving (35% (n=21) female; 65% (n=39) male). Participants were randomly assigned to A, B and C treatments. A percentage of 83% of the

Figure 1.3: Combined used of multiple devices (tablet and smartphone). to foster reflective practice in-action

participants (n=50) reported to own a smartphone. The remaining 17% (n=10) reported to own a regular mobile phone. 60% (n=36) of the participants reported to be familiar with eBooks while the remaining 40% (n=24) reported not to be familiar with eBooks. A 5 euros book-voucher rewarded their participation in the experiment.

Materials

Participants completed a survey-form on demographics, technology expertise, and, previous knowledge on energy-efficient driving. Afterwards they should simultaneously use a smartphone and an eBook to go through the contents (See figure 1.3). The eBook was specifically created for this experiment and consisted in the following 3 chapters:

1. Welcome and introduction (2 pages). Included the instructions to accomplish the exercise and use of the tools.
2. Fifteen hints on energy-efficient driving (15 pages). These pages contained short texts (mean 70 words per page) enriched with five videos (mean duration 1 min), one audio, nine pictures and one chart.
3. Post-questionnaire (1 page). Included a link to the online form.

There were two variations of the same eBook, one for group A, and another common for groups B and C. The only difference between these two was that the book from group A included of QR code for each of the fifteen hints on energy-efficient driving (See figure 1.4).

Additionally, every participant was given a smartphone with ARLearn installed in it Ternier et al. (2012a,b); Schmitz et al. (2013); Börner et al. (2013b). This tool provides a main screen where all the incoming notifications are received (figure 1.5a). When a message is opened the content of the message prompting the user to reflect and report is displayed. Figure 1.5b illustrates the message prompted to participants from group A. Figure 1.5c illustrates the message prompted to participants from group B. Notifications to group C where analogous to group B (Figure 1.5c), but with the microphone recording disabled.

Design

The design of the notifications is varied on two dimensions: Timing and Response.

Figure 1.4: Multimedia eco-driving eBook for Group A

Table 1.3: Group treatments in the energy-efficient driving experiment

Table here

First, notifications received on mobile devices are expected to have different effects depending on when the notification is received. Notifications can be received randomly at any moment during the experiment, on regular time basis (e.g. every day after lunch-time, receive a notification prompting to reflect how healthy was the food), or triggered by the accomplishment of an event (e.g. every time I watch TV more than one hour, receive a notification asking how much I read during the week). The authors expected that the reflection exercise would unleash a different cognitive process depending on when the notification happens.

Second, notifications prompting users to reflect are expected to have different effects depending on how the reporting exercise has to be performed. This work examines the effects on knowledge and motivation when the reporting of the reflective practice is accomplished in two different forms: 1) the user externalizes his/her reflection with an audio recording on a mobile device; 2) the user reflects but does not externalize the knowledge recording it. We expect a different effect based on the variation on how students formulate what they learned in the creation of their own synthesis.

Procedure

This experiment took place during July 2013 in individual sessions of maximum one hour. Firstly, participants had five minutes to complete a short questionnaire about demographics, experience on energy-efficient driving and familiarity with mobile technologies. Secondly, participants had 50 minutes to read the eBook supported and complete the post-questionnaire. Finally in a less than 5 minutes interview, participants were asked for impressions on "how was the learning experience?".

The experiment on energy-efficient driving contemplated the three treatments illustrated in Table 1.3 and described as follows:

- Group A. Twenty participants were invited to read the eBook in these terms: "On the following pages you find so called QR codes. You can scan these codes and by scanning you collect this information into your personal storage. Please collect at least the 6 most important tips with your mobile device. You will be able to later on receive the collected information in a summary email". Whenever the participants chose to scan one of them, a new item appeared in the message inbox (figure 1.5a). By opening it, the user not only

collected the multimedia item from the eBook to the mobile device, but also received a request to reflect on "What are the most important things you have learned so far?. Why did you collect/scan this specific hint, and How would you explain this to a friend?" and externalize this reflection with an audio annotation (figure 1.1b).

- Group B. Twenty participants were invited to read the eBook in these terms: "In the following experiment you will read an eBook about energy-efficient driving and we want to research how well this eBook is suited to learn about this topic. When you start the game you will receive questions for reflection on a regular schedule, please follow the instructions on the mobile device". Users received a new item in their message inbox every three minutes (figure 1.5a). By opening it the user was encouraged to reflect and record it in an audio speech recording in these terms "It's time to reflect! Think about: What are the most important things you have learned so far?; How would you explain these to a friend? Record the explanation in an audio annotation" (figure 1.5c)
- Group C. Twenty participants were invited to read the eBook in the same terms as participants from group B. Users received a new item in their message inbox every three minutes (figure 1.5a). By opening it the user was encouraged to reflect in the same terms as the participants in group B. Nevertheless, this treatment did not consider recording an audio annotation on the reflection exercise.

Measure instruments

The experiment on energy-efficient driving contemplated three measures. (1) A pre-questionnaire gathered demographics, technology expertise, and, previous knowledge on energy-efficient driving. (2) A post-questionnaire measuring two variables:

- Knowledge. This survey included one multiple-choice question for each of the hints described in the book. They were concrete questions on what has been learned reading the eBook.
- Motivation. Four variables from the Intrinsic Motivation Inventory (IMI) Ryan (1982) were used to measure differences in motivation among the groups. Seven-valued likert scales were used to rate the following variables: Interest/enjoyment was measured with seven items. Perceived competence was measured with six items. Pressure/tension with five items. Value/usefulness

Table 1.4: Overall Means (M), Standard Deviations (SD), and Reliability Coefficient (Cronbach's Alpha) for intrinsic motivation variables

Table here

Table 1.5: Group-clustered measures for intrinsic motivation variables

Table here

Table 1.6: Pollas

with six items. The Cronbach's alpha coefficient was calculated to measure the internal consistency in the four variables of motivation.

(3) Short face-to-face interviews gathered open impressions from users on: *"how was the learning experience?"*.

II Results

Reflecting in-action with mobile notifications

This study aimed to explore the effects in motivation and knowledge of different variations of mobile notifications triggered when reading an eBook of energy-efficient driving.

The Cronbach's alpha coefficient concluded in reliable values for all the IMI variables ranging from .83 to .87 (See Table 1.4). Calculating the overall mean in the variables of intrinsic motivation resulted in higher values for group C in contrast to the lower values for group A. Table 1.5 illustrates the answers clustered into its four variables. On the one hand, group C resulted in higher values for *"interest"*and *"competence"*, group B resulted in higher values for *"pressure"*, and group A resulted in higher values of *"usefulness"*. On the other hand, group A resulted in the lower values for *"interest"*, *"competence"*and *"pressure"*. Group C resulted in the lower values for usefulness.

Knowledge was measured upon the number of correct answers in the 15-items questionnaire. Table 1.7 illustrates mean and standard deviations values for the three different treatments. The experiment resulted in higher mean values for group C in contrast to group B that resulted in lower mean values.

An analysis of variance (ANOVA) was performed with the aim to identify differences between means and their variation among the groups. As illustrated in Table 1.8,

Figure 1.5: Experiment to foster reflection in-action through mobile notifications

Table 1.7: Group-clustered measures for knowledge variable

Table here

Table 1.8: Results from ANOVA test for intrinsic motivation and knowledge variables

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the ANOVA test resulted in non-significant values ($Pr(>F) > 0.05$) for IMI variables. Nevertheless, the ANOVA test resulted in a remarkable variation in *"knowledge"*for group C with respect to the other groups.

The results obtained in the ANOVA test for the variable of *"knowledge"*show differences that cannot be assured to be determinant.

When the participants had finished the activity, they were offered the possibility to provide open feedback by answering to the question *"how was the learning experience?"*. This interview raised the following insights to be taken into account:

1. Combining multiple devices is not always well accepted. A participant from group C (#42) reported that *"the only effect from the mobile device was to disturb and disrupt my learning experience"*. Similar, #44 from group C reported that *"when I am focused on reading, receiving messages is more disruptive than helpful"*. Participant #29 reported that *"asynchronous notifications were annoying since they came in the middle of the reading and I had to stop reading the eBook, to open the incoming notification in the mobile device"*.

2. Participants self-organized their reading approaching the sections of the book depending on the type of multimedia formats. This eBook contained texts, pictures, videos and audios distributed among the fifteen hints. E.g. participant #33 reported that she had first read the text from the eBook and after that watched the sequence of videos. Participants from group A adopted different behaviours when reading the eBook. As the participants of this group were assigned to scan, collect and reflect on their six preferred hints, some participants decided to scan (on the go) as they were advancing on the book. Others decided to read the whole book first, and then sequentially scan, collect and reflect on their preferred set of items.

3. Iterating notifications with the same content produces a drastic polarization of user's interest on the notification. Some users from groups B and C reported that after the second notification they gave up reading when they noticed every notification contained the same instruction (#12, #42).

4. Participants that were aimed to self-reflect and not actively externalize the audio speech on the mobile device (group C) sometimes skipped to perform the self-reflection exercise. The fact that participants from group C were

not prompted to record the exercise of reflection resulted in less disrupted readings for this group. Participant #30 *"after the second notification, as I was not asked to actively do something I did not reflect and kept on reading"*.

1.4 Discussion and conclusions

This manuscript has explored the use of mobile notifications to foster reflection on learning by presenting the results of two studies that involved 97 participants in total. Mobile notifications have been used to support users in the competence of *"learning to learn"*[3] raising reflection and awareness as trigger to foster understanding (meta-learning) [5] and motivation on learning.

The formative study provides an instantiation in which smartphones are used to stimulate meta-learning about the common life as a learner. A proportion of pupils accepted and was able to use their personal smartphone for *"serious"*messages coming from the researcher outside the school hours. Whilst it can seem obvious, this precondition does not speak for itself. Hardy and Haywood (2008) show that even when undergraduates do have a good level of IT competence and confidence, they tend to be conservative in their approaches maintaining a clear separation between technologies for learning and for social networking. On the other hand, Jones et al. (2008) report that, despite being unaccustomed to using their mobile phones for academic study, students willingly accepted SMS reminders focused on time management and not on learning consolidation from their tutor via a bulk texting service. Nevertheless, subsequent identical notifications prompting the student to reflect are not well accepted. This observation can be concluded not only from the results of the decreasing rate of participation in the first study, but also in the second experiment were participants reported not paying attention to succeeding notifications when they noticed that the first two were identical. Hence the effects of subsequent non-identical notifications should be explored in further investigation.

This study suggests that learners willing to stop and think about *"how"*and *"what"*they learn, still perceive the school as the major channel of learning. These reports contrast with the ones from users that voluntarily decided not to take part in the daily reflective exercise in which the majority of them perceived Internet as the main channel of learning. Indeed, schools' monopoly over learning processes seems to be challenged by the emergence of a rich ecosystem outside school walls as heralded by the Internet (Table 1.1). Of particular concern for future research is to ascertain how school and other channels of education contribute to youth's intellectual growth Facer (2011). In such an investigation, student's voice is obviously

critical. And to express it, young people will have to learn to think as learners in order to provide valuable accounts of what they are living as learners in multiple contexts. This need to be able to reflect on the common life as learners takes us back to the what motivated this study: defining methods and designing tools to make learning an object of attention and reflection.

Three findings emerge from the formative study regarding reflective practice in students' common life:

1. There is no anchored habit of the students to see themselves as learners and to develop a *"professional"*awareness (see section *"Familiarity with reflective practice"*) about their daily activity/job at school (Ertmer and Newby (1996); Sternberg (1998)) and the learning opportunities after school. This study demonstrates that notifications instantiated in personal mobile devices can be used by secondary school students to make them focus and reflect on their autobiography as a learner. These signals and the subsequent reflection moments are expected to trigger actions from student´s side towards the development of an identity as a learner. From the authors' perspective, there are two main factors in the design of mobile notifications that positively contribute to foster reflection: first, the personal mobile device is perceived by students as an intimate channel in which they have the privacy to deal with meta-learning aspects beyond the content being learned; second, in contrast to traditional orientation-talks from teachers or parents, the fact that students know that notifications are coming from an external non-usual source (researchers) makes them focus more intensively on the offer to reflect;

2. Providing time to perform reflective activities on this topic is appreciated by about half of the participants (see section *"Appreciation of reflective practice"*) for reasons relating to sense-making and professional development as a student. Notifications prompting to reflect seem to be effective when they are received at the end of the day (8pm) so that students can make one step back and think how their learning day was;

3. The stop-and-think beacons offered here are considered as useless or superfluous by a good deal of students, even when they have been designed not to last a long time (for similar attitudes of rejection of reflection see Watkins (2001); Johnson and Sherlock (2009)). The fact that the content of the notifications delivered for every iteration was always the same, as well as the fact that the notifications were received always at the same time of the day (8pm) could increase the perception of superfluousness. Further research must be done on how these notifications are perceived when both the content and the delivery time are not (so) predictable.

Overall these findings contribute to understanding the basic notions of learning, self-reflection and the use of triggers from mobile devices in the context of a formal educational institution. The convergence of information, communication and broadcasting technologies is one of the major determinants of the need for lifelong learning (Longworth (2013)). Both studies presented in this paper provide relevant insights on the use of technology to foster key competences for lifelong learning [3]: *"digital competence"* by combining the use of mobile devices and tablets for meta-learning; *"learning to learn"* by providing users new channels to reflect on their learning.

The formative study shows that simplistic instantiations of notifications via SMS are useful to promote reflective practice on the learning activities scattered throughout the day (reflection on-action [6]).

The second experiment implements one step forward in the complexity of the notifications by combining the use of different devices and interactions to reflect in-action. Our assumption was that the group with the highest number of interactions (group A), using user-triggered notifications combined with the externalization of knowledge and the collection of learning objects, would result in increased values for knowledge and motivation.

The results obtained in the experimental study suggest that asynchronous notifications prompting users to reflect are not well accepted while multitasking with another learning activity. Automatic notifications resulted in disruptive learning experiences where few participants found an added value to this treatment. In contrast, participants were able to customize their learning experience by adapting the order to read, reflect and externalize when the notifications should be delivered (scanning the QR code). In fact, none of the participants reported that user-launched notifications were a cause of disruptive learning experiences. This finding reinforces the outcome from our previous study where participants preferred to receive user-triggered (event-based) notifications to *"stop and think"*, in contrast to asynchronous notifications [18]. Measures of knowledge and intrinsic motivation resulted in non-significant differences between the group that approached user-launched notifications (group A) and the groups that approached automatic notifications (groups B and C).

The fifth research question of this manuscript aimed to gain insight on whether the externalization of knowledge using audio speech recordings on a mobile device (groups A and B) would result in increased values for knowledge and motivation compared to the participants that did not do it. This was not the case since differences between the groups were not significant. Contrary, the results presented above only put forward for consideration that within the group of participants

that received the same type of notifications (groups A and C with scheduled-based notifications), the participants that did not externalize knowledge (group C) could score better in this variable. This finding confirms some previous insights on the limitations of *"thinking aloud"*to understand learning (Young (2009)) pinpointing to issues of participant´s reactivity, participant´s verbal abilities, and whether the information provided by think-aloud accurately reflects thinking. In our specific case, we can add *"digital competence"*as one more limitation in the fact that participants had to deal with both a non-familiar app and smartphone to externalize their reflections. The interviews after the experiment confirmed this disruption where some of the participants reported not to be used to this smartphone model (Sony Xperia), the operating system (Android 4.01), or the mobile app (ARLearn Ternier et al. (2012b)). Wilson (1994) states that *"while it is not claimed that think aloud provides a complete insight into the human mind, it certainly is a useful tool available to the researcher"*. The results obtained in this experiment are inconclusive and do not confirm that externalizing the knowledge on mobile devices might be beneficial towards better motivation and knowledge. Nevertheless, we strongly believe that this negative effect was caused by the fact that participants had to deal with a non-familiar environment to record their audio (See fig. 1.5b and 1.5c). Hence, participants lost the focus on what they were reading while handling the mobile tool to externalize the reflection exercise. In the future we suggest further research on the benefits and limitations of thinking aloud providing tools that are familiar to the participants so they can naturally record an audio without losing the thread on what the user had learnt.

The last research question is built upon the assumption that the reflection preceding the collection of a learning object awakes a motivation on the learning topic. Some participants highlighted the usefulness of collecting the hints on energy-efficient driving to be further read and studied in more detail when they had time. Nevertheless, this is not the focus of this study. Measures of knowledge and intrinsic motivation resulted in non-significant differences between the group that collected learning objects and the groups that did not. There is a need to quantify whether the reflection that precedes the collection of learning objects has an impact on learning in further research.

The sample in the formative study decreased for technical reasons but also for reasons probably tied to the importance granted to reflection. These reasons should be investigated for themselves and a subsequent study should be carried out with bigger samples. This study also prompted students only four times. More investigation is needed into the tension of intruding into the pupils' out-of-school time. It has already been shown that many university students do not like their academic studies to intrude into personal time or their social networking activities.

The answers reported in the interview of the experimental study point to differences between users with regard to familiarity with mobile technologies (*"digital competence"*[3]). In this scenario, users who were not so agile interacting with devices, were more focused on the mobile interaction than on the reflection exercise itself. Likewise, the time devoted by the participants to accomplish the activity in the experimental study was quite unbalanced (even of participants with the same treatment). Some participants were faster reading the eBook so they were still receiving notifications prompting to reflect when they had completed the task. Participants with least digital competence received all the notifications when they were reading the first two pages of the book. Hence, this experiment uncovers familiarity with the tools as one of the main limitations to accomplish seamless learning experiences. We also highlight the short duration (one hour per user) of the learning experience, and the high frequency of the notifications received during the experiment as limitations of this study. We suggest further research on the effects of notifications in longitudinal studies when they are received in personal mobile devices.

These results relight the need for support in Mobile Seamless Learning (MSL) experiences [22], in particular, the combined use of multiple device types (MSL7), seamless switching between multiple learning tasks (MSL8) (such as data collection, analysis and communication), encompassing formal and informal learning (MSL1) and knowledge synthesis (MSL9). We will further advance this research not only with further studies aiming to foster reflective practice on meta-learning [18], but also implementing tools to promote self-regulation Tabuenca et al. (2014b), facilitate natural interactions (Tabuenca et al. (2014c)), and enable seamless learning experiences via ambient learning displays (Börner et al. (2013a)).

Part III

Tap it again, Sam: harmonizing personal environments towards lifelong learning

Chapter 2

Tap it again, Sam: harmonizing personal environments towards lifelong learning

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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2.1 Introduction

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Part IV

Binding daily physical environments to learning activities with mobile and sensor technology

Chapter 3

Binding Daily Physical Environments To Learning Activities With Mobile And Sensor Technology

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.

This chapter is published as: Börner, D., Kalz, M., and Specht, M. (2011). Thinking outside the box – A vision on ambient learning displays. *International Journal of Technology Enhanced Learning*, 3(6), 627–642.

3.1 Introduction

I Using NFC Sensor Tags For Bridging Seams And Natural Interaction

3.2 Design Of The NFC LearnTracker

I Self-Regulation Across Contexts With Mobile Learning Analytics

Set Goals

Perform Learning Activities

Monitor Learning Activities

II An Open Source Architecture Facilitating Extension Across NFC Readers And NFC tags

3.3 Formative Evaluation

3.4 Conclusions And Future Work

Part V

Supporting Lifelong Learners To Build Personal Learning Ecologies In Daily Physical Spaces

Chapter 4

Supporting Lifelong Learners To Build Personal Learning Ecologies In Daily Physical Spaces

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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4.1 Introduction

4.2 A Questionnaire For Lifelong Learners

I Method

II Results

The concept of 'lifelong learning'

Patterns based on type of device, lifelong learners' behaviour and timing

Linking locations, activities and ways of interaction with mobile devices

At home

Waiting

On-the-move

Gender

Missing Learning Activities

Difficulties When Learning With Mobile Devices

4.3 A Review On Smart Objects For Learning

I At home

In the the classroom & workplace

4.4 Conclusions

Part VI

Where Is My Time? Identifying Productive Time Of Lifelong Learners For Effective Feedback Services

Chapter 5

Where Is My Time? Identifying Productive Time of Lifelong Learners for Effective Feedback Services

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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5.1 Introduction

5.2 A Classification Framework For Modelling Lifelong Learners' Day

I Receive notification

II Dispatch question

III Provide answer

5.3 Qualitative study

I Introduction

II Method

Participants

Materials

Design

Procedure

III Results

5.4 Discussion and Conclusions

Part VII

OER in the Mobile Era: Content Repositories' Features for Mobile Devices and Future Trends

Chapter 6

OER in the Mobile Era: Content Repositories' Features for Mobile Devices and Future Trends

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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6.1 Introduction

6.2 Literature review on learning objects for mobile devices

I Method

II Results

Creation of contents

Publication of contents

Content allocation

Standards for content packaging, delivery and sequencing

Architectures framing mobile content delivery

Content repositories and ubiquitous computing

6.3 A survey to OER repository owners on mobile usage

I Method

II Results

6.4 What mobile features are providing the main OER repositories

6.5 Discussion and Conclusions

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Summary[1]

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

[1] 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.