Embedding Moodle into Ubiquitous Computing Environments

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Abstract

Over the past years several attempts for connecting Moodle to mobile devices have been made. The past attempts are focused on making the functions of the virtual learning environment (VLE) available on mobile devices. For this particular form of enabling access to learning the mobile device is limited to a special display type. Features of personalizing learning experiences based on the learners' mobility and their changing information needs in different contexts is typically not considered by these developments. This conceptual paper analyses the underlying concepts for a system-architecture for device adaption for mobile learning. The analysis focuses on educational and technical perspectives for system design. The results of this analysis are transferred for integrating Moodle into ubiquitous computing environments.

Keywords

Device adaptation, personalisation, ubiquitous computing, virtual learning environments

1. INTRODUCTION

Over the past years several attempts for connecting Moodle to mobile devices have been made (Yingling, 2006; Moodle4iPhones, 2010). Similar attempts can be found for commercial products (Blackboard, 2010; Giuntilabs, 2010; IMC AG, 2010) and other open source solutions (Silverio, 2008; Ghiglione, 2009). The past attempts are focused on making the functions of the virtual learning environment (VLE) available on mobile devices. For this particular form of enabling access to learning the mobile device is limited to a special display type. Features of personalizing learning experiences based on the learners' mobility and their changing information needs in and across contexts is typically not considered by these developments.

This conceptual paper analyses an IT infrastructure-architecture for integrating aspects of learner-mobility with Moodle in order to blend relevant information from the VLE with spatial learning environments that are equipped with ubiquitous computing systems (Morken & Divitini, 2005). Mobile devices can serve as sensors for context detection as well as anchors for on-going personal interaction of learners with the VLE across contexts. This architecture is applied in a set of Moodle extensions.

The rationale of the presented architecture is based on the notion that learning processes are continuous processes that take place in different environments. These environments can be virtual or spatial. From an educational viewpoint the different learning environments are not disconnected. The connectedness of virtual and spatial learning environments has been widely reflected and discussed using the term "blended learning". Until today, blending VLEs and spatial learning environments heavily rely on teacher mediation and are not well supported by the IT infrastructure.

The recent developments of mobile interfaces to VLEs illustrate the underlying problem. Although mobile devices can now be used to deliver learning resources to learners almost anywhere and anytime, the major VLEs do not enable instructors to contextualise learning activities. For example, by default it is not possible for instructors to anchor learning activities or resources to locations. If an instructor intends to utilize the VLE information during a fieldtrip, it is up to the instructor to communicate the relations between locations, learning activities, and resources.

Embedding a VLE into a ubiquitous computing environment raises another problem. By design, most VLEs have interfaces that allow a single system-user to interact through a single interface at a time. This means that every user of a VLE requires a dedicated interface that is bound to a single device. Even if a user has several devices at hand, the interfaces will represent the same learning environment rather than expanding it. Opposite to this single-user single-interface metaphor, ubiquitous computing environments typically follow a multi-user multi-interface design. This means that different system-users may share interfaces, or that they can distribute information across different interfaces.

In addition to the prominent device specific content delivery for improving the access to learning two problems areas have to be considered for *device adaptation*. The first problem is the contextualisation of learning and learning support. The second problem is the orchestration of interfaces and educational services.

The aspects delivery, contextualisation, and orchestration are important for mobile learning. By integrating them into VLE functionality eases the use of mobile learning approaches by a larger educational audience.

This paper discusses the underlying concepts of a system-architecture for device adaption for mobile learning. The analysis focuses on educational and technical perspectives for system design. The results of this analysis are transferred for integrating Moodle into a ubiquitous computing environment.

2. RESEARCH OBJECTIVE

The primary objective of the present research is to adapt technology-equipped spatial learning environments to the learning tasks of a learner or a group of learners, where the contextualised learning tasks are defined in a VLE. This special form of device adaptation is based on the observation that the different learning environments are not separated elements of the learning process. Instead, the different environments are interconnected and contribute to the same process. Constructing and managing the connections between the different learning environments with different technologies is typically left to teachers and instructors. Through a technological integration it is expected that the complexity of managing blended learning across learning environments can be reduced.

The primary objective of the present research has two subordinate technical objectives that are within the scope of this paper.

1. Extending the context-awareness of Moodle.
2. Integrating Moodle into technology-equipped spatial learning environments.

It is necessary to extend Moodle with functions that add generic context-awareness to the system, because the VLE needs to be aware of the learners' contexts in order to select and to adapt information for the spatial learning environment. Learner support in spatial learning environments requires that the entire environment is aware of *implicit* factors that define a learning setting, whereas learning activities in most contemporary VLEs are structured by the *explicit* arrangement of resources and services as well as on the *explicit* navigation of the learners through these arrangements.

On top of generic context-awareness, additional interfaces for Moodle are required for embedding the VLE into a ubiquitous computing environment. These interfaces have to reflect that the learners no longer access the VLE through a single communication channel, but through a heterogeneous infrastructure of personal and shared devices. Therefore, the VLE needs to be able to distribute information across different user-interfaces rather than just responding to a page-request from a web-browser.

3. BACKGROUND

Although the objectives appear to be primarily technology-centred, the technology requires an educational and instructional foundation. For this purpose this section emphasizes three conceptual pillars.

1. Personalisation and contextualisation
2. Orchestrating learning
3. Supporting learner-mobility

3.1 Personalisation and Contextualisation

Personalisation is increasingly important in technology-enhanced learning. However, personalised learning is not unambiguous. Two general viewpoints on personalisation can be identified. The first viewpoint defines personalised learning as individualised and tailored educational experiences (Aroyo et al., 2006). The personal dimension in this viewpoint is directed towards facilitated educational processes that are unique to a learner. The second viewpoint emphasises the personal relevancy and involvement of individuals in learning process (Verpoorten, et al., 2009). From this perspective, personalised learning refers to those processes that support learners to take responsibility and control over their learning and enable them to reflect on the learning on a meta-cognitive level.

The two perspectives on personalisation are not mutually exclusive: learner-controlled learning processes may lead to unique learning experiences and automatically adapted educational environments may support deeper learning experiences that help them to feel more responsible for their learning. However, learner-control does not promote a specific kind of educational approach, because learner-control and unique learning experiences can be provided in mass education, and fully tailored educational processes can be provided without leaving any control to the learner.

Contextualisation can be considered as a more generic form of personalisation. The concept of contextualising broadens the scope from the individual learner controlling a self-centred process to the learner in a context that includes co-influencing relations between elements within the same context (Zimmermann, Specht, & Lorenz, 2005, Zimmermann, Lorenz, & Oppermann, 2007). Context-ualisation can be considered as adaptation processes that support learners to identify, create, and maintain relations between elements including themselves in and across contexts.

Device adaptation has been previously discussed largely as a special form of "adaptive presentation" (Brusilovsky, 2001). The related research (Ally, Lin, McGreal, & Woo, 2005; Bomsdorf, 2005; Elson, Reynolds, & Chapman, 2007; Hassan & Al-Sadi, 2009; Herder & van Dijk, 2002; Martín, Carro, & Rodríguez, 2006) highlights the need for adapting learning resources and services to the user interfaces of mobile devices. This type of adaptation primarily focuses on device characteristics and is combined with additional adaptive approaches for personalisation. However, device adaptation is restricted to adaptive presentation. In order to widening the scope of device adaptation the following definition is proposed.

Device adaptation describes approaches of adaptive systems that include device characteristics in their adaptation strategy.

This definition suggests another type of device adaptation besides including previously suggested approaches: *adaptive device selection*. Adaptive device selection describes approaches that identify and select devices for user interaction based on contextual parameters. This type of adaptation is of particular interest for combining mobile learning with ubiquitous computing (Specht, 2009). Figure 1 shows a multi-interface environment with personal and social interfaces.

Figure 1: Multi-interface environment with personal (front) and social interfaces (back).

3.2 Orchestrating Learning

Dillenbourg (2007) identifies three dimensions that are involved in orchestration. The first dimension is the interplay of learning activities at different social planes. The planes are bound to the social connectedness of learners on the activity level and can include the individual, collaborative, collective (class wide) activities. The second dimension is the timing of an educational script. Timing refers to the interrelation of the learning activities and the transitions from one activity to another. The last dimension is the focus on the learning process. Focus refers to emphasizing or hiding aspects of the learning objective in order to guide the students' attention. Integrating these dimensions allows teachers to manage the available environment for learning.

Orchestrating learning is closely related to educational design. According to Goodyear & Yang (2009) educational design "is largely a matter of thinking about good learning tasks (good things for learners to do) and about the physical and human resources that can help learners to succeed with such tasks." (Goodyear & Yang, 2009: p. 169) When analyzing educational designs it is required to distinguish between learning outcomes, learning activities, and learning tasks. "Learning outcomes are the durable, intended, and unintended cognitive, affective, and psychomotor consequences of the learner's activity (mental or physical)." (Goodyear & Yang, 2009: p. 169) These outcomes are the result of what the learner does. In other words, learning outcomes are the direct consequence of the activity of a learner. According to Goodyear & Yang, learning activities are based on the learner's interpretation of the requirements of learning tasks. Teachers or instructional designers typically define learning tasks.

Van Merriënboer, Clark, & de Croock (2002) structure the educational design process into four interrelated components: learning tasks, supportive information, just-in-time information, and part-task practice. Learning tasks are provided to learners in order to stimulate whole-task experiences for constructing knowledge (schema and rules). Supportive information is supportive with respect to the learning tasks. It bridges between learners' prior knowledge and the learning task. Just-in-time information refers to procedural rules of the educational design and the related information for communicating these rules to learners. Part-task practice items "are provided to learners in order to promote rule automation for selected recurrent aspects of the whole complex skill" (Van Merriënboer, Clark, & de Croock, 2002: p. 43). Educational design processes rely on aligning these components for generating coherent learning experiences that lead to higher transfer performance then designs that do not take all components into account.

While educational design is indirect to the learning situation, orchestrating learning implies also the direct management of performing learning tasks during runtime. From this viewpoint orchestrating learning includes the personalisation and the adaptation of learning tasks, because personalisation and adaptation refer to management decisions related to dynamic task arrangements in a learning environment. However, educational design and orchestrating learning go beyond defining rules for learning. Both concepts build on three pillars: learning tasks (and sub-tasks), learning environments, and procedural rules. Orchestrating learning crucially depends on the coordination of the relations between these pillars.

Koper & Specht (2008) argue that related coordination problems can be identified at different levels of complexity of the learning environment. New tools and services can enrich the learning environment in ways that meet the learning needs of lifelong learners. Furthermore, the authors emphasize the connectedness of services and roles in learner communities at the different levels.

Based on the research on educational design, orchestrating learning refers to the coordination and the alignment of four dimensions.

- The roles that are involved in the educational activities and the interplay of the different social planes (Dillenbourg, 2007).
- The learning tasks include the main learning tasks (Goodyear & Yang, 2009) supportive tasks, and part tasks (Van Merriënboer, Clark, & de Croock, 2002).
- The learning environment includes all kinds of services, knowledge resources (Koper & Specht,

2008), just-in-time and supportive information (Van Merriënboer, Clark, & de Croock, 2002), and the characteristics of the spatial learning environment.

- The rules and directives for the educational process, including the timing and the educational focus (Koper & Specht, 2008).

The typical VLE approach to orchestrating learning is to arrange the resources and services around a specific learning task. This leads to appropriate results because the VLE controls the relation of learning tasks and the related environmental elements. In other words, the environment cannot change without changing the learning task.

From the more general instructional design perspective roles, learning tasks, and the learning environment mutually influence each other within the conditions defined by the rules that guide the educational process. For example, possible learning tasks can be constrained by the presence or absence of other participants in an environment. Therefore, mechanisms for integrating a VLE into ubiquitous computing environments are required in order to reflect the mutual relationships between the elements of educational processes.

3.3 Supporting Learner-mobility

The ambient information channel (AICHE) model (Specht, 2009) is an attempt to integrate concepts of context-aware computing and the relations of different aspects of mobile learning. It allows analysing generic patterns of contextual interactions and contextual learning support. These patterns include context matching as well as context construction. The patters can be used to provide generic solutions for conflict resolution, so the rules and the directives of an instructional design can focus on relevant aspects of the educational process. Furthermore, the AICHE model helps to describe and to analyse contextual information needs of mobile learners.

The core facets of the AICHE model are information channels and physical artefacts. By abstracting information channels from their presentation modes it is possible to model the arrangement and re-arrangement of information channels depending on a learner's context. The arrangement of information channels means that a channel can be temporarily bound to physical artefacts, e.g. a TV set, a mobile phone, or a desktop computer. The underlying contextualisation pattern is based on the process of aggregation, enrichment, synchronisation, and framing of information. Aggregation refers to the collection and processing of low-level sensor data into operational information. The enrichment process connects the operational information to the related entities of a process. During the synchronisation process related (enriched) entities are identified. This process results in a matching of entities. E.g., the location of a learner is matched with the location of artefacts through related location metadata. The framing process is mostly related to feedback and the stimulation of meta-cognitive processes. This process is related to the construction of educational contexts.

The separation of devices and information channels in the AICHE model opens a new perspective on mobile learning: the mobility of learners takes place in an ecosystem of technologies. In the last decade devices and technologies were increasingly converging. The "Internet of Things" (Sarma, Brock, & Ashton, 2000) and ubiquitous computing (Weiser & Brown, 1996) slowly become part of normal life in industrial nations. An increasing number of home entertainment devices, including TV sets and digital picture frames, are already equipped with network connectivity and can integrate seamlessly into home computing networks and connect to services on the Internet. Following the AICHE model the different devices are possible endpoints for information channels. However, the setting of the different devices varies and creates specific requirements for information provisioning. These requirements go beyond the personal computing paradigm (Thacker, McCreight, Lampson, Sproull, & Boggs, 1979).

Previous research has suggested a layered system-model for contextualisation and adaptation for technology-enhanced learning support (Zimmermann, Specht, & Lorenz, 2005; Verpoorten et al., 2009). The model describes an information-processing pipeline. This pipeline is based on the input from a sensor network. The tracked data is diverted for information presentation as well as for the control processes for system adaptation. Table 1 shows the relation of the proposed layers with the related data processing functions.

Table 1: Relation between the architecture layers and data processing for context-aware and adaptive systems

Architecture layers	Data processing functions
1. Sensor layer	Data collection
2. Semantic layer	Information selection
3a. Control layer	Information arrangement
3b. Control layer	Information application
4. Indicator layer	Information presentation

For categorising different approaches to mobile learning that reflects the different characteristics of information technologies a simple framework is proposed. This framework has two main dimensions that characterise a device: the mobility dimension and the ownership dimension. The mobility dimension distinguishes between mobile and stationary technologies. Mobile technologies are easy to transport by a single person and allow the usage while being mobile. Stationary technologies refer to technologies that require some installation before they can be used or transported. The ownership dimension separates personal and social technologies. Personal technologies are designed for being used by a single person. E.g., mobile phones, PDA, and personal computers are personal technologies. Social technologies allow simultaneous information access for groups. Interactive billboards and public information screens are examples of social technologies.

By connecting the two dimensions four technology clusters can be indentified (Figure 2). The first cluster is related to stationary personal technologies. This cluster is directly related to personal computing. The second cluster is the mobile personal technology cluster. This cluster groups technologies such as PDA, mobile phones, and mobile gaming devices. The third cluster integrates stationary social technologies, such as electronic billboards or interactive information walls. Finally, the fourth cluster refers to mobile social technologies. As an example of such technologies may serve portable speaker systems through which sound experiences can be shared.

Device mobility		Primary device usage	
		Personal	Social
	Stationary	Personal Computer	Smart board, public information screen
	Mobile	Mobile phone, PDA	Mobile Audio Speaker System (excl. head-phones)

Figure 2: Dimensions of mobile learning support

The framework allows focusing on the characteristics of technology use when conceptualising and analysing contextualisation of information channels. While recent developments focus primarily on personal devices the present research seeks to extend the scope to stationary social systems.

4. CONNECTING MOODLE TO SPATIAL LEARNING ENVIRONMENTS

This section describes the architecture for integrating Moodle into a ubiquitous computing environment. Figure 3 shows the different components of the presented solution in relation to the conceptual model for context-aware and adaptive systems.

The core requirement for the implementation was to avoid changes of the core application interface. This has been achieved through Moodle's plug-in interface. The rectangles in Figure 3 indicate the plug-ins, which were implemented. This approach was only violated by extending the internal function for activity tracking in order to trigger data aggregation and to control processes depending on the learners' activity. The logging function is shown as a rectangle with rounded corners. This small extension (a single line of code) automatically allows any activities using existing Moodle plug-ins to trigger personalisation and adaptation processes in external plug-ins.
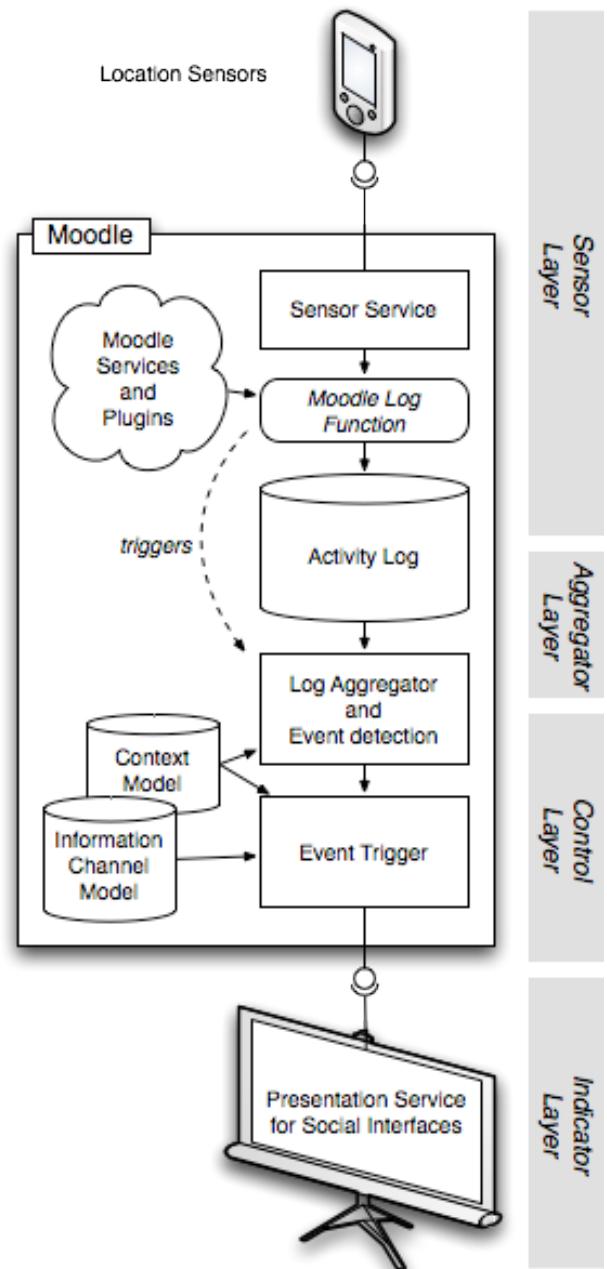

Figure 3: Component architecture and data processing schema

4.1 Data collection from external sensors

For connecting Moodle to ubiquitous computing environments the system has been analysed based on the layered system-model. The first step for contextualisation and adaptation is the data collection. This data is required for user and context modelling.

Although Moodle does not support external sensors, the system provides a central tracking component. This system component is used by all system components and extensions for activity logging. This component is typically only available to instructors for monitoring learner activities. By implementing a service interface based on the

Moodle plug-in application interface the internal tracking component is exposed to external sensor networks.

The initial use of the data collection service is to return the location of learners to the system using the geo-location data that is offered by web-browsers of recent mobile devices. This data is collected through Moodle's mobile user-interface. Together with asynchronous service calls this is the foundation for integrating location awareness into Moodle. Wireless Network triangulation capabilities that are present in an increasing number of mobile handheld devices even allows indoor location tracking where GPS signals are usually inaccurate or unavailable.

4.2 Data aggregation and information selection

The second layer of the system-model is the semantic layer. This layer defines the context model and performs data selection and data aggregation operations on the tracked sensor data. Moodle itself has no data selection functions other than exposing the raw tracking information to system administrators and course instructors. Therefore, an aggregation plug-in has been implemented for Moodle. This plug-in provides selected views on the tracked data. Each view can get accessed through named aggregators that relate to a data selection and processing function on the activity logs.

In order to provide data privacy, only authenticated system users have access to these aggregators. Furthermore, this plug-in implements social perspectives on the data. A social perspective provides learners with anonymous information about their peers. The different social perspectives are "self", "friends" (learners who are in the personal address book), "group members" (in case of group work), and "peers" (other learners who are enrolled in the same courses). The social perspectives provide basic metrics to the learners in order to relate their personal activity to the activity of their peers.

The aggregators of the semantic layer are dynamic factors of the context model that is used for adapting social interfaces in the spatial learning environment. The control layer uses the output of the aggregators for identifying the activity context of the learners, and for adapting the learning environment if necessary.

4.3 Context modelling

In addition to dynamic context factors context identification and adaptation require static reference factors. These static factors of the context model are considered partly as elements of a learning environment and partly as rules of an instructional design. Therefore, a teacher or instructor has to be able to anchor information channels to locations in the spatial learning environment. An information channel can be any resource or service (e.g., a discussion forum) that is part of a Moodle course.

Anchoring information-channels to ubiquitous computing environments requires two additional models.

1. A context model

2. An information-channel model.

The context model is shared across all courses in the Moodle instance. This model defines the name of a context, the extent of a context, and the devices that are available in that context.

The name of a context is needed so teachers and instructors can later link their information channels to the location. For example, a name of a context can be the number of a room where certain learning activities should be performed.

The extent of a context is used to identify if a learner matches the context. This defines the outer boundaries of a location, so it is possible to distinguish if a learner is present at a location. If the extent of a context refers to a parameter in a specific course, then this context is limited to a single course. Locations are normally modelled as global contexts.

The devices that are available in a context are modelled as URLs to services that can be used for sending a particular information type to a device. Additionally every URL has an indicator if it provides a personal or a social interface, and if the service is capable to integrate the same information channels for different learners.

The information channel model connects resources or services to a location. The information channel model can be defined for an entire course or bound to a single learning activity. If a resource or a particular service is anchored to a location it is no longer available to the learners as part of the normal course structure.

4.4 Controlling contextualisation

The control layer uses the dynamic context model based on the learners' tracking information, the context model, and the information-channel model for arranging the information that has to be available in the learners' context. If a new context has been identified for a learner, then the related course and, if defined, the related learning activity is activated, too. Furthermore, all information channels are selected for the active context.

The information arrangement of the control layer is implemented as a set of internal functions that are invoked by the higher order interfaces during the information application process. A learner is considered to be in a context, if the extent of the context matches the dynamic context factors of the learner. The context matching is performed on the contextual dimensions that are defined by the AICHE model.

The information application is implemented as a web-service interface that allows reading the context state of a learner from a Moodle system. The information application layer of this control process triggers the information arrangement and if this process results in any information channels for a context this service will select appropriate interfaces for each information channel and forward the channel to the external device.

4.5 Information presentation

Every context can offer a range of interfaces for presenting information channels. Each interface in a ubiquitous

computing environment has to be considered as an independent information system that has special capabilities and that can be addressed through a common network infrastructure. The different capabilities of an interface are implemented as separate web-services to which the control layer can forward the information channels.

Because ubiquitous computing environments are in principal multi-user environments, the underlying web-services are responsible for integrating the information for different learners in case of shared interfaces or lock a system to a single learner in case of personal interfaces. How this integration is done depends on the type of information channel. For example, tagging channels of different learners might be integrated into a share tag cloud that can be used to discuss shared interests. In contrary, video streams on a shared screen will be cued and played sequentially.

4.6 Triggering the device adaptation process

In normal single-interface web-usage of Moodle, the activation of an adaptation processes is triggered by learners' requests to the web-server of the VLE. In these settings the adaptation process is bound to the interactions of a learner with the VLE. If a component expects external updates in this setting, then it has to check periodically for them. This so-called *pull*-approach has been implemented by a few extensions of the Moodle system, such as the implementation of a chat tool. More commonly Moodle components do not expect any changes for the interface between two interactions. The single-interface metaphor assures that the adaptation process is related to the learner activity and that the number of requests per learner is reasonable.

In multi-interface settings the *pull*-approach quickly becomes inefficient, because a learner may has several information channels connected to different devices in an environment but interacts only with one at a time. As any interaction may affect information that is on display at another interface, all active interfaces have to check periodically for updates for all connected learners. In order to avoid unnecessary network overhead, the presented architecture *pushes* updates to the connected interfaces if needed.

In order to detect updates, the service of the control layer is triggered whenever data is added to the Moodle logs. However, context tests are only performed if the added data entry influences a dynamic context factor for the learner. Consequently, updates for the related information channels are only pushed if real updates become available.

5. CONCLUSION AND FUTURE WORK

This conceptual paper analysed the underlying concepts for a system-architecture for device adaption for mobile learning. The analysis focuses on educational and technical perspectives for system design. The results of this analysis are transferred for integrating Moodle into ubiquitous computing environments.

Integrating Moodle into ubiquitous computing environments required the development of new service interfaces for the system. Nevertheless, the central user-tracking component of Moodle has been reused. This has the main benefit that this architecture allows to use other learner activities within the VLE as contextualizing factors for the adaptation process because all operations for contextualisation and adaptation are built on top of this component. Furthermore, the architecture can be easily transferred to other VLE, because most systems have similar learner-tracking components.

Given the technical scope of this study further research is needed with regard to the effect of this extended perspective on device adaptation for personalized learning and instructional design.

6. ACKNOWLEDGMENTS

7. REFERENCES

Ally, M., Lin, F., McGreal, R., & Woo, B., 2005. An intelligent agent for adapting and delivering electronic course materials to mobile learners. *Proceedings of the 4th World Conference on mLearning (mlearn2005)*, Cape Town, ZA, 25-28 Oct 2005. [Online] Available at http://mlearning.noe-kaleidoscope.org/public/mlearn2005/www.mlearn.org.za/-CD/papers/Ally-an%20intelligent.pdf

Aroyo, L., Dolog, P., Houben, G., Kravcik, M., Naeve, A., Nilsson, M., et al., 2006. Interoperability in Personalized Adaptive Learning. *Educational Technology & Society*, 9, 2, pp. 4-18.

Blackboard Inc., 2010. Blackboard Mobile Learn. [Online] Available at http://www.blackboard.com/resources/mobile/-Whats_in_MobileLearn.pdf

Bomsdorf, B., 2005. Adaptation of Learning Spaces: Supporting Ubiquitous Learning in Higher Distance Education. In: *Mobile computing and ambient intelligence : The Challenge of Multimedia. Computers & graphics 30.2006,5. - Dagstuhl Seminar Proceedings 05181* . Elsevier, Orlando.

Brusilovsky, P., 2001. Adaptive hypermedia. *User Modeling and User-Adapted Interaction*, 11, pp. 87-110.

Dillenbourg, P., 2008. Integrating technologies into educational ecosystems. *Distance Education*, 29, 2, pp. 127-140.

Elson, B., Reynolds, P. Chapman, C., 2007. Blueprint for an adaptive training – virtual learning environment (ADAPT-VLE) for the training of dentists. In A. Norman & J. Pearce (Eds.). *Making the connections, Conference Proceedings of the 6th annual international conference on mobile learning* (pp 51-60). Melbourne, AU, 16-19 Oct. 2007.

Ghiglione, E., 2009. LAMS on iPhone/iPod Touch. [Online]. Available at http://wiki.lamsfoundation.org/display/-lams/iPhone

Giuntilabs, 2010. *eXact Mobile: An integrated solution for content, information and knowledge dissemination and ubiquitous personalised learning.* [Online] Available at http://www.giuntilabs.com/download.php?over=xarticles&down=985

Goodyear, P., & Yang, D., 2009. Patterns and pattern languages in educational design. In L. Lockyer, S. Bennett, S. Agostinho

& B. Harper (Eds.), *Handbook of Research on Learning Design and Learning Objects: Issues, Applications and Technologies* (pp. 167-187). Hershey PA: IGI Global.

Hassan, M. & Al-Sadi, J., 2009. A new mobile learning adaptation model. *International Journal of Interactive Mobile Technologies*, 3, 4, pp. 4-7.

Herder, E., & van Dijk, B., 2002. Personalized adaptation to device characteristics. In P. De Bra, P. Brusilovsky, & R. Conejo (Eds.). *Adaptive Hypermedia* (AH2002), pp. 598-692.

IMC AG, 2010. *CLIX Mobile Learning features*. [Online] Available at http://www.im-c.com/en/products/learning-management-system/product-overview/mobile-learning/

Koper, R., & Specht, M., 2008. Ten-Competence: Life-Long Competence Development and Learning. In M-A. Cicilia (Ed.), *Competencies in Organizational e-learning: concepts and tools* (pp. 234-252). Hershey: IGI-Global.

Martín, E., Carro, R.M, & Rodrígez, P., 2006. A mechanism to support context-based adaptation in m-learning. In W. Neidl & K. Tochtermann (eds.). *EC-TEL 2006*, LNCS4227, pp 302-315.

Moodle4iPhones, 2010. *Project homepage*. [Online] Available at http://iphone.moodle.com.au/index.php

Morken, E.M, & Divitini, M., 2005. Blending mobile and ambient technologies to support mobility in practice based education: a case of teacher education. *Proceedings of the 4th World Conference on mLearning* (mlearn2005), Cape Town, ZA, 25-28 Oct 2005. [Online] Available at http://mlearning.noe-kaleidoscope.org/public/-mlearn2005/www.mlearn.org.za/CD/papers/divitini-1.pdf

Sarma, S., Brock, D. L., & Ashton, K., 2000. *The networked physical world, proposals for engineering the next generation of computing, commerce & automatic-identification*. [Online] Cambridge, MA. Retrieved from http://www.autoidlabs.org/single-view/dir/article/6/93/-page.html.

Silverio, G., 2008. *The Sakai PDA portal*. [Online] Available at http://gonzalosilverio.wordpress.com/2008/11/20/the-sakai-pda-portal/

Specht, M., 2009. *Learning in a technology enhanced world*. Heerlen: Open University of the Netherlands.

Thacker, C. P., McCreight, E. M., Lampson, B. W., Sproull, R. F., & Boggs, D. R., 1979. Alto: A personal computer. In D. P. Siewiorek, C. G. Bell, & A. Newell (eds.), *Computer Structures: Principles and Examples* (pp. 549-572). New York, NY: McGraw-Hill.

Weiser, M., & Brown, J. S., 1996. The coming age of calm technology. *Technology*, 01, July, pp 1-17.

van Merriënboer, J.J.G., Clark, R.E., de Croock, M.B.M., 2002. Blueprints for Complex Learning: The 4C/ID-Model. *Educational Technology, Research and Development*, 50, 4, 39-64.

Verpoorten, D., et al, 2009. Personalisation of Learning in Virtual Learning Environments. In U. Cress, V. Dimitrova & M. Specht (Eds.), *Learning in the Synergy of Multiple Disciplines* (pp. 52-66). Lecture Notes in Computer Science Vol. 5794. Berlin: Springer-Verlag.

Yingling, M., 2006. Mobile Moodle. Journal of Computing Sciences in Colleges, 21(6), 280-281.

Zimmermann, A., Lorenz, A., & Oppermann, R., 2007. An operational definition of context. In B. Kokinov, D.C. Richardson, T.R. Roth-Berghofer, & L. Vieu (Eds.), *Modeling and using context* (pp. 558-571). Berlin, Heidelberg: Springer.

Zimmermann, A., Specht, M., & Lorenz, A., 2005. Personalisation and context management. *User Modeling and User-Adapted Interaction* , 15, 3-4, pp. 275-302.