Context modeling to support the design of mobile learning

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ABSTRACT
The evolution of information and communication technologies in the last three decades has had an impact in all aspects of human activities. Learning has also been subject of these changes. Current research efforts in the field of mobile learning have been in many cases guided by a learner-centered approach. Context awareness and content adaptivity are crucial components in mobile learning environments. One important challenge is how to design and implement technological tools and methods to support them. In order to tackle this challenge, learners' context should be defined. In this paper, we describe our current efforts regarding how to model context in mobile learning activities. We introduce a time dependent context model based on a three pole structure that can be used to design and support context awareness in mobile learning environments. We illustrate its applicability in four different cases where mobile learning activities and implementations have been guided by the use of this model.

Categories and Subject Descriptors
K.3.1 [**Computers and Education**]: Computer Uses in Education – *collaborative learning, computer-assisted instruction (CAI), computer-managed instruction (CMI), distance learning*

General Terms
Management, Design, Theory,

Keywords
Mobile learning, context model, context awareness, content adaptivity, contextual data model.

1. INTRODUCTION
Technological development has had a strong impact in the way people learn. This can be noticed especially due to a large number of implementations of technology enhanced learning environments over the last two decades. These implementations have primarily been led by different pedagogical approaches that mainly were rooted in constructivist learning theories.

These theories have been based on two main streams: cognitive constructivism (derived form [20] work on theory of knowledge) and social-cultural constructivism (derived from [27] work on cognitive psychology). Moreover, as suggested by the work of [8], the main component of the constructive learning view could be summarized as the "*learner actively constructs knowledge*" in interaction with material systems, discussion with other participants and reflection upon concepts in the specific domain. Brown and Duguid [4] complement this view by defining learning as a social activity that is primarily based on collaboration. Collaboration can occur between actors (i.e. learners) and with the help of artifacts [10]. Recent mobile learning projects have primarily focused in developing new tools (primarily based on mobile devices) that can enhance the collaboration and knowledge acquisition. Such cases can be found in some of the projects described by [23]. The common denominator of these projects is the tendency for the adoption of a true learner-centered design approach. These trends emerged mainly because due to rapid evolution of the mobile (i.e. personalized) technologies. For achieving fully learner-centered environments the use of context awareness and content adaptivity is crucial, as suggested by [22]. Mobile learning environments offer new possibilities for bringing computational support into the context of learning and present a challenge regarding the integration of mobile context-aware computing in these new educational settings [25]. In these situations, achieving context awareness is crucial for supporting true learner-centered activities. Context awareness offer opportunities to embed learning in natural environments [21]. Content adaptivity enables the reusability of learning content in different settings (i.e. learning contexts). Therefore, the main research question to be discussed in this paper is formulated as follows: "*How can context be used as a design input for supporting awareness and content adaptivity in mobile learning environments?*"

This article describes a context model that tries to address those issues connected to context awareness and content adaptivity in mobile learning environments. This paper proceeds further by discussing those issues related to learning and context. Furthermore, it continues with the presentation of a context model that could be used as a tool to support the design of mobile learning activities. This is illustrated by presenting a couple of empirical examples that have been designed and inspired by this model. In the concluding remarks, we suggest how the development of a data schema inspired by this context model could be used to support content adaptivity.

2. LEARNING AND CONTEXT

Success in achieving learner-centered approach in technology enhanced learning implementations is intimately related with considerations regarding the learners' context. Research has increasingly indicated that the inability of students to apply concepts learned in formal contexts is in many cases due to the abstraction and decontextualization of the learning [3]. But it is not the abstraction of knowledge as such that distracts learners, but that the abstractions are not illuminated with examples in context. The importance of context in mobile learning era has been highlighted by work conducted by [9] where he finds that context is one of the factors that can be used for categorizing mobile learning. Understanding and learning is a product of context and activity. Moreover the importance of context in knowledge creation and learning was suggested by the work of [18] where he suggests that knowledge creation (thus understanding) is directly affected by context. Moreover, situated cognition argues that learning is simplified by embedding concepts in the context in which they will be used [4]. This clearly indicates the importance of considering context for technology enhanced learning implementations. But despite this, defining context has been and still is a challenge. Different authors have attempted to tackle this challenge by providing numerous definition of context. For example, [11] defined context as "*aspects of current situation*", which is a very broad definition. Another definition from a computational perspective is given by [5] where he defines context as "*elements of the user's environment which the computer knows about*". Another human centric definition of the context is given by [7] where they define context as "*any information that can be used to characterize the situation of entities (i.e. whether person, place or object)*". [26] defines context as a combination of environment, activities and participants. While in mobile learning community context is defined as *"context should be seen not as a shell that surrounds the learner at a given time and location, but as a dynamic entity, constructed by the interactions between learners and their environment"* [24]. The wide variety of approaches to define what context is indicates its complexity. Moreover, the problem of context awareness in learning activities can not be tackled only from the definitions perspective. In the next section, we try to develop our own definition of context, followed by a model that describes this effort.

3. CONTEXT MODELING

According to [6] modeling is *"an activity, a cognitive activity in which we think about and make models to describe how devices or objects of interest behave"*. Therefore, the main idea behind models is to ease the understanding of complex phenomena.

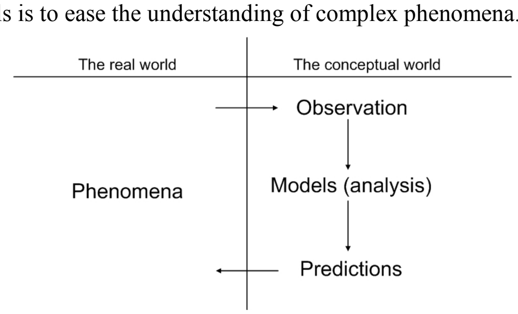

Figure 1. Relation between real and conceptual world in scientific methods [6]

The heterogeneity in the definitions of context illustrates its complexity; therefore the creation of a model would potentially be beneficial. The link between "real world" and "conceptual world" is based primarily on models [6]. This interconnection is illustrated in figure 1.Context is a real world phenomenon that needs to be understood for being able to provide support for context awareness. Context observations lead toward definitions, which should be accompanied with analysis that would eventually result in models. These models should facilitate the understanding of context, but still detailed enough so it could be used to predict (i.e. show awareness for) phenomena (i.e. context). Having in mind the idea behind modeling and different context definitions, we have defined context slightly different, and accompanied it with a model representation. Our definition is leaded form the activity perspective that is scalable to computational attributes. Thus, we define context as *"information and content in use to support a specific activity (being individual or collaborative) in a particular physical environment at a specific time"*. Our definition of context relies upon a three-pole structure. The three-pole structure consists of the following attributes; location/environment attributes, activity/task attributes and personal/interpersonal attributes and this placed in a certain time. The attributes of this structure are interdependent, meaning that information about who the user is, where the user is, what the user is doing and the interplay between these activities needs to become valuable inputs to the design process of mobile learning activities. Figure 2 makes an attempt to illustrate our context model applicable to mobile learning. The time dimension shows the changeability of context in different moments (represented as frames in figure 2). Time becomes important especially when it comes to historical dependencies as suggested by [13].

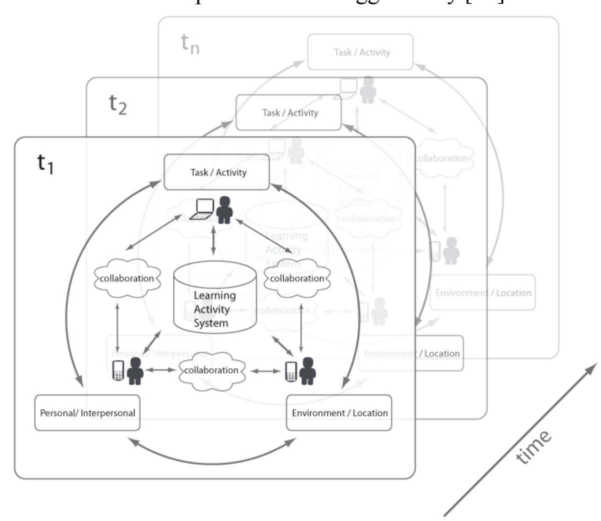

Figure 2. Conceptual context model for designing learning activities

From the system perspective a central component of this model is the Learning Activity System, best described as a computational system and content repository that provides the technological infrastructure for integrating educational content into the context that learning activity is taking place. Winters and Price [29] claim also that the context in which an activity is taking place is crucial for learning. The participants interact with the Learning Activity System and with each other, thus promoting different modes of collaboration. The surrounding circle of this conceptual model basically defines one frame of context where the activities are taking place. The frame is defined by a time snapshoot. Therefore context as complex phenomena is a represented as a series of time differentiated frames.

From a technical perspective, the implementation of the Learning Activity System relies upon the use of different software components and mobile technologies, as well as sensors in order to contextually support different learning activities and collaboration.

Inspired by dimensional analysis in mathematical modelling, we consider that this approach can be applicable for context modelling as well. According to [15], dimensional analysis is defined as "*a method by which we deduce information about a phenomenon from the single premise that the phenomenon can be described by a dimensionally correct equation among certain variables*". Therefore our context model can be described by terms of dimensional analysis. Dimensions of context are defined by three pole structures and time. The time dimension becomes important especially when it comes to historical dependencies that could affect user profile (i.e. personal/interpersonal attributes), activity and its location/environment. The space part of our context model (i.e. context frame of our conceptual model) built upon the three-pole structure can be represented by coordinative axis as illustrated in figure 3. Each axis represents one of the attributes of our conceptual model of context. It should be noticed that this represents just one snapshoot (i.e. frame) at a certain time (t_1).

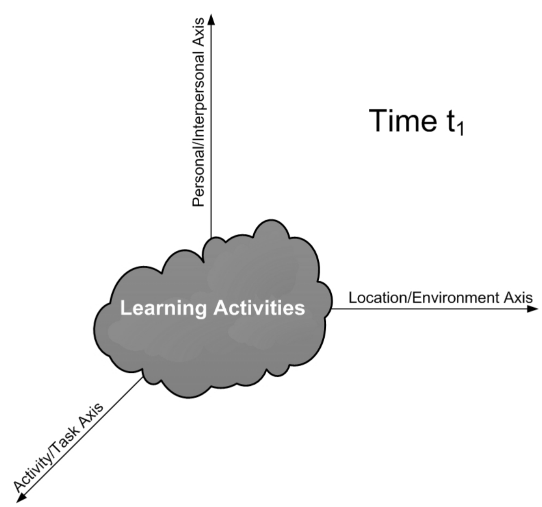

Figure 3. Dimensional analysis of context

If we perceive the context of learning activity as a spatial function and we use the three pole attributes of the context, then the mathematical representation of our context definition can be expressed according to the following function:

$$f\ (X_{LE},\ Y_{PI},\ Z_{AT},\ t)$$

This basically means that context is a function of location/environment attributes (X_{LE}), Personal/Interpersonal attributes (Y_{PI}) and Activity/Task attributes (Z_{AT}) and time. While one frame of our conceptual model illustrated in figure 2, represents time integration of this function. Thus if the context function is represented by $f\ (X_{LE},\ Y_{PI},\ Z_{AT},\ t)$, one context frame could be defined as:

$$\int_{t_{i-1}}^{t_i} f\ (X_{LE},\ Y_{PI},\ Z_{AT},\ t)dt$$

Where i values can vary between 1 and n. Therefore, one frame of this conceptual model is represented as a function that is time independent. This function could be represented as:

$$g\ (X_{LE},\ Y_{PI},\ Z_{AT})$$

Each frame of the contextual model could be represented as function of X_{LE}, Y_{PI} and Z_{AT} complex variables. Each of these complex variables is functions of sub variables as well. These dependencies are presented in the table I:

Table 1. Context dimensions

Context $f\ (X_{LE},\ Y_{PI},\ Z_{AT},\ t)$		
Location/Environment $u\ (X_{LE})$	Personal/interpersonal $v\ (Y_{PI})$	Activity/Task $e\ (Z_{AT})$
X_{LE} = longitude latitude building humidity temp. light int. etc.	Y_{PI} = person group age membership collaboration etc.	Z_{AT} = type rules subjects inv. outcome division etc.

As this table shows, the context is basically comprised of infinite dimension that could be grouped in three major (location/environment, activity/task and personal/interpersonal) functions. McCarthy [17] also claims that context dimensions are infinite. Each of these sub variables basically represents a computational instance that is retrievable by the means of sensors and actuators. Today trends in mobile technologies tend toward embedding capabilities of different sensors and actuators into single device. This scale of integration enables new computational paradigm to emerge based on users' context. Therefore using this dimensional representation of context, it is possible to use this model as design input for providing context awareness support.

4. USING CONTEXT AS DESIGN INPUT

Our main research efforts in the area of mobile learning have been designed and developed as a part of two research projects namely: MUSIS and AMULETS. The MUSIS project was designed to explore, identify and develop a number of innovative mobile services with rich multimedia content to be distributed over wireless networks in university campuses. In the AMULETS project we are exploring how teachers can develop and implement novel educational scenarios combining outdoors and indoors activities that use ubiquitous computing technologies together with stationary computers. As a part of these two projects we have run several trials related to learning across different contexts.

These trials took place during the last two years period and included trials with knowledge workers (i.e. librarians), primary school children and students.

4.1 Växjö Library trial

Ten librarians at Växjö Public library were equipped with Nokia 6630 smart phones with 128MB and with GPRS access (free of charge) to the MUSIS channels (including text, audio and video material) for a four weeks trial during the period October-November 2005. We used different data gathering techniques in order to identify and define the contextual attribute which would be used as design input for development of the new mobile service. Based on questionnaires, interviews and observations, it was evident that librarians spend most of the time while providing information regarding the content of the books to users. The contextual attribute used here was division of labor between librarians so they can offer better services to their users. Having in mind this, a audio book review service was developed that enabled librarians to share their book experiences with their follow colleagues. This was done by the means of mobile multicasting of audio content. In general after the trial librarians were positive about the audio book reviews service.

4.2 Bergunda School Trial

The second trial took place at Bergunda School (near Växjö, Sweden) in the surrounding nature in the spring 2006. Students were divided into six groups and each group was roughly four children. The activity was conducted in six sequential sessions with each group. The students in each group were equipped with a smartphone (Nokia 6630) for event triggering (semacode reading) and content delivery. They also had a GPS enabled smartphone (HP iPAQ 6515) for navigational purposes and content generation and documentation. The activities were divided into three stages including a pre-activity, a field activity and a post activity. The pre-activity comprised a series of lectures about the forest that were carried out by the teacher in the classroom setting during several days. During this stage children learned about different aspects of the forest and basic knowledge that could be used to identify the trees in the nature. The children needed to go to the closest forest located 200 meters southeast from the school yard in order to identify a particular kind of tree (among three possible choices) that corresponded to the specific one presented during the pre-activity at the school. In order to solve this task, the children needed to scan the correct semacode tag attached to the right tree. Each one of the three trees had a different semacode an in case of an incorrect choice of tree, additional information was delivered to the smartphone giving the children new information to solve the task. During the entire field activity the children documented their activities by taking pictures and making videos. The post activities took place in the classroom where all groups presented and discussed the content created during the trial while this content was tailored to a specific location. The contextual attributes used as design input where location and division of labor.

4.3 Växjö Square Trial

This trial took place at the main square and at the museum of history in the city of Växjö in the fall 2006. The overall activity was divided into three sessions over two days. The students were divided in three groups, each group consisting of ten children. Additionally, each group was divided in two subgroups of five students, where one subgroup was working indoors in the museum while the other group was outdoors in the city square.

The outdoor subgroup was equipped with three smartphones (Nokia 6630) for content delivery, content generation, instant messaging and decoding the visual semacodes tags. The indoor subgroup was equipped with a laptop computer equipped with a GPRS connection and a mobile handset for still photography. Teacher students supervised the groups during the activities. While the outdoor subgroup was in the field, the indoor subgroup was in the museum. In order to successful accomplish all the educational tasks the subgroups needed to collaborate using mobile technologies in a variety of ways.

The main activity of this trial was carried out in the form of a collaborative game-like activity that was organized as a set of missions taking place in different locations and across different time periods related to local and regional history. The activities were designed around the group collaboration to solve the challenges for each task. The contextual attributes used as design input in this trial were also: location and division of labor.

4.4 Teacher students trial

This trial took place on campus at Växjö University in the spring of 2007. 17 teacher students participated, divided into 4 groups. Each of these groups was divided into 2 subgroups. The field groups were equipped with two smart phones, one for game control and information and one for digital documentation. The control smartphone was used with semacodes for the control of the learning activities and for sending messages via a semacode tag and the second phone automatically delivered the photographs and audio files to base camp once the students took an image or finished recording. The field activities focused around the identification of 4 different families of trees, where the outdoor group collected data (images, video and audio files) via the smartphones. The indoor group analyzed the images, audio, and texts in order to determine with the support of a tree taxonomy instrument to which family the tree belongs to according to leaf buds, bark colour, and other environmental factors. For this third trial we further refined the learning activity by running simultaneous trials with four groups and splitting the indoor and outdoor sessions between them, enabling all the students to experience the different roles and aspects of the trial. In this trial we tried to scale down the number of devices and control the communication to be more effective.

4.5 Applying the context model

The main idea behind applying our context model is the possibility of identifying certain sub variables that could lead to the design and development of contextual activities, thus resulting in a kind of context awareness support from the system side. Use of context as a design input has been suggested by different authors especially when it comes to defining user centered systems [2]. Technology enhaced learning systems represents a user centered system, the use of context as a design input would probably improve learners' experience, thus potentially resulting in truly learner-centered approach. Except for the first trial (that took place inside, in the workplace), in the other trials the physical location of the users affected the design of the learning activities. Location played the important role while designing learning activities.The learning content has been generated in a way that its meaning was tailored with the location of the users. The tailoring of learning content was done with the help of sensors (mainly visual codes and GPS data). In the first trial, the main design input was derived from the librarians' activity (i.e. activity/task attributes). Audio book reviews system was built upon the fact that most of the time while working librarians' spent offering information to users about content of the book. In the other trials, beside location (location/environment attributes) also activity/task attributes (i.e. division of labour) was also used as a design input. The division of labour served as a collaboration catalyst. In general, the model described in the previous section was helpful for identifying and dissecting context attributes, thus enabling them to be used as a design input. Usage of context attributes as a design input for technology enhanced learning represents a first step towards achieving context awareness in mobile learning settings. For detailed elaboration of these trials, including details of technical implementation please referee to our previous work [14].

5. CONTENT ADAPTIVITY

Nowadays, mobile devices have reached a very high level of hardware embeddings. Under these circumstances, every mobile learner has the potential of becoming a content creator. During our trials, most of the learners have created different types of digital content. The need for that content to be categorized for later reuse is evident. A typical way for doing this was using metadata structures. Manual metadata generation is a time demanding and annoying task for the users and therefore it should be avoided [28]. Having this in mind, we should try to embed as much as possible metadata automatically, based on the sensor data available (like GPS, temperature, date, time etc.). Using the three pole attribute of our context definition, it is possible to build a taxonomy for the categorization of learner generated content. In this way, the reuse of content should be based on the context. Main idea behind adaptivty in the systems relies only in the adoption of the database content [31]. For achieving context awareness there is a need for something more, there is need for semantic reusability of content. Therefore for content adaptivity there is a strong need for content "semantic personalization" that would be based on the context. The context model described earlier potentially enables this approach of adaptivity. Each frame of contextual model represents basically a fully described XML document, consisted of four nodes. Three nodes represent the three pole structure while the fourth node of the XML file represents the snapshoot attribute (i.e. date and time). The data structure based on the context model is designed according to XML schema illustrated in figure 4. The XML Schema provides a method to create precise descriptors that enable unambiguous declaration of data and their attributes. This enables semantic reusability of content based on contextual metadata. Therefore the context data model can be used as metadata that accompanies the content (such as pictures, audio files, video files, document etc) that can be shared and distributed in the mobile learning activities. Using metadata for context capturing has been advocated also by the work of [15] where they argue that context-based metadata could improve and enhance movement and transmission of the content. Having a structural organization of the context model based on the three-pole structure, as metadata for different types of content can support and enhance the collaboration between participants in mobile settings. Thus enabling active knowledge creation based on collaboration supported by content adaptivity and reusability.

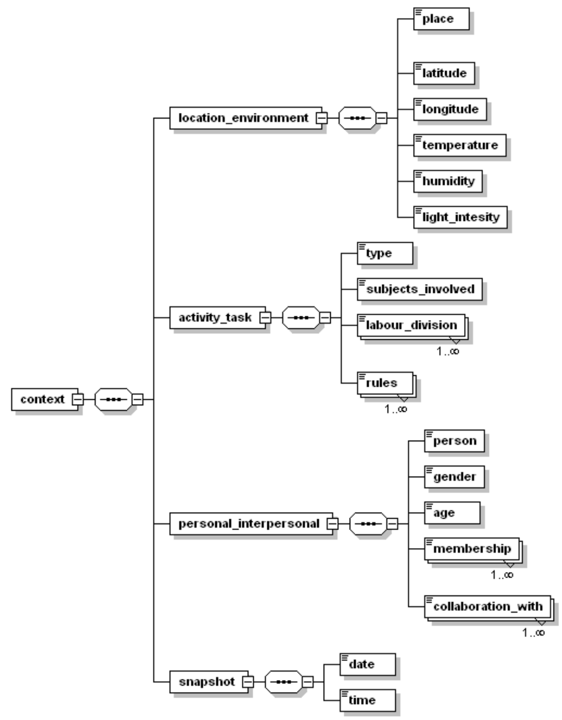

Figure 4. Context XML Schema.

6. CONCLUSIONS AND FURTHER WORK

Context awareness in learning systems can be perceived as an interactive model between learners' and services, and their definition is usually based on an ontological perspective [30]. Our context model complements this view by applying a dimensional analysis perspective that dissects the complexity of the learning context into a set of attributes that can be used as an input for the design of mobile learning activities. Recent research conducted by [12] has identified "location" and "time" as the most important parameters for describing the learners' context. Our context model relies on a three pole structure that besides "location/environment" and "time", brings also into account attributes such as the user's activity/task and his/her profile. The outcome of our efforts suggested that applying the different context attributes of this model (such as "division of labor") as a design input seemed to be important for enhancing the learners' experience. The use of the "division of labor" attribute as a design input primarily served as a collaboration catalyst among learners. The organization of learning content packages is another important issue to consider while supporting context awareness in mobile learning environments. Balatsoukas and colleagues [1] claims that "*the lack of concrete specifications can impede interoperable exchange of content packages*" is the main problem in this field. The context XML Schema derived from our context model could be used as a tool for organizing metadata, thus potentially enabling semantic reusability of these content packages. Awareness in mobile learning implementations requires that learning activities are embedded into the learners' context. Having this in mind and inspired by our context model, we can suggest some initial recommendations to support context awareness in mobile learning:

- Learning and exploration should be placed in authentic settings (i.e. location/environment)
- Collaboration should be promoted by the active construction of knowledge (attributes from learners' activities/tasks should be part of design input)
- Content used and created during these learning activities should be enhanced with contextual metadata for allowing sharing and reusability

In the coming two years, we will continue to explore and further develop our current line of research as part of a new research project in which we will investigate how the ideas of seamless learning and "open inquiry" can by supported by features of context awareness and content adaptivity.

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