Viable and Portable Architecture for Pervasive Learning Spaces

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ABSTRACT

A Pervasive Learning Space (PLS) uses context-awareness to link a virtual world with real world objects. We define viability as the extent to which a given PLS can be adapted to different purposes, and portability to be the extent to which a given PLS can be transferred to a new physical context. Heroes of Koskenniska is a game-based PLS combining mobile technology and a wireless sensor network in a forest context to raise the environmental awareness in a Biosphere Reserve in Finland. The game was built upon a screen-based architecture, and our analysis shows that it has higher portability and viability than a selection of related PLSs. The screen-based architecture is highly viable and portable because it is based on the model-view-controller division. Our preliminary observations indicate that the game helps to increase visitor count of the area and to promote interaction between visitors and nature.

Categories and Subject Descriptors

K.3.1.b [**Computers and education**]: Computer Uses in Education—*CAI*; K.8.0 [**General**]: Games; J.9.a [**Mobile applications**]: Location-dependent and sensitive; D.2.13 [**Reusable Software**]: Reuse models;

Keywords

pervasive learning, wireless sensor network, environmental education, model-view-controller, viability, portability, biosphere reserve

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1. INTRODUCTION

A Biosphere Reserve is an international conservation designation given by UNESCO under its Programme on Man and the Biosphere (MAB)[1]. The North Karelian Biosphere Reserve (NKBR), located in Eastern Finland, is surrounded by coniferous forests, hills, mires and lakes. Popular recreational activities at NKBR include hiking, fishing, hunting and camping, but the region has not offered interactive tools to promote interaction between nature and the people.

To establish a connection between people and nature in NKBR we explored the use of Pervasive Learning Spaces (PLSs) to facilitate environmental education in a forest context. In this paper we propose a *screen-based architecture* for PLSs that are *viable* and *portable* (Section 2.1). The proposed architecture was used to implement a game-based PLS *Heroes of Koskenniska* which combines mobile and sensor technologies with environmental education. The context of the game is the Koskenniska Mill and Inn Museum area located by the Shepherd's Trail, a 37km hiking trail in NKBR. Heroes of Koskenniska is a role-playing game that is inspired by Kalevala, the Finnish national epic. The player is guided by Ukko, the High God, in the battle against Hiisi, the malicious and horrifying spirit that seeks to destroy the environment and the people. The aim of the game is to teach the learner about the environment and cultural history in a fun and exciting way while real-time sensor readings are used to provide contextual background data of the physical context.

There are several learning applications which have been developed for environmental education (e.g. [17], [6], [5]) but they lack viability and portability from both the system and content developer's perspectives. To overcome this deficiency, we developed Heroes of Koskenniska by using a screen-based architecture where each screen has a separate data structure (*model*), rendering mechanism (*view*) and *controller*. In this paper we first show the need for a PLS at NKBR. Then we present the Heroes of Koskenniska game followed by a description of the screen-based architecture and an analysis of the viability and portability of existing PLSs. We finally analyse the architecture's advantages and

[1]http://www.unesco.org/mab

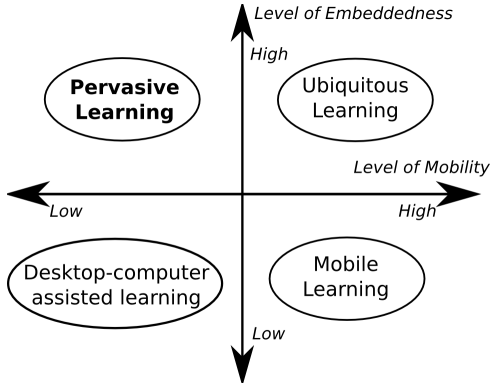


Figure 1: Types of learning according to levels of mobility and embeddedness [11]

disadvantages based on the experiences gained during the development and testing processes.

2. BACKGROUND

2.1 Concept definitions

Pervasive learning refers to type of learning where the real and virtual worlds are bridged for learning activities in a specific context. Pervasive learning differs from ubiquitous learning in terms of mobility (Figure 1), and the systems which implement the pervasive learning paradigm are referred to as *pervasive learning spaces* (PLS, also pervasive learning *environments*). This means that whereas ubiquitous learning merely refers to "everywhere" learning, a pervasive learning experience varies according to place, time and the learner's activity. PLSs make effective use of the physical environment as the context for learning, content for learning and system resources [7]. We use the term *spaces* rather than *environments* so as not to confuse the acronym PLE with Personal Learning Environments. Examples of projects that qualify as PLSs are LieksaMyst [10], Environmental Detectives [6] and Insectopia [13]. A more detailed account on the differences between pervasive and ubiquitous learning is available in [8].

PLSs are tightly connected to the surroundings, and the various assets of the context are used as learning resources. PLSs use some level of context-awareness to provide context-sensitive learning materials and activities [7]. The higher the level of context-awareness, the more blurred is the boundary between the real and virtual worlds as the system becomes aware of the learner's status and can adjust its operations accordingly. The level of context-awareness also partly dictates how immersive the learning experience can become.

Because a PLS is always created for a specific context and for a specific purpose, we recognise the need of a system architecture that supports flexible creation of PLSs for various contexts and purposes. Such an architecture can be measured through the aspects of *viability* and *portability*, defined as follows.

- *Viability*: the extent to which a given PLS can be adapted to the requirements of new stakeholders or subject matter.
- *Portability*: the extent to which a given PLS can be transferred to a new physical context without adjusting the technical implementation.

If the architecture of a PLS allows flexible creation of new types of applications in the same physical context with minimal development efforts, then the viability is high, whereas if the PLS is suited only for a single purpose the viability is low. A PLS has low portability if deployment to another location requires significant changes to the underlying system (e.g. rules, concepts, equipment). High portability allows the PLS to be transfered between physical contexts with minimal changes to the original implementation. For example, GreenSweeper [5] (Section 6) has low viability because it has been designed for a single purpose only. However, its portability is high as it can be deployed in any urban context.

2.2 Rationale

A Biosphere Reserve is a site recognized under UNESCO's Man and the Biosphere Programme, which innovates and demonstrates approaches to conservation and sustainable development. In 2009 there were 553 Biosphere Reserves in 107 countries around the world. One of the most important goals of research activities done in NKBR and other Biosphere Reserves around the world is to *bridge the gap between nature and people*. Traditionally this challenge has been tackled by hiking trails and other outdoor activities. A major challenge remains in how to facilitate the visitors' and NKBR inhabitants' understanding of nature. Information boards have been used, but their space, format and possibilities for interaction are limited. To make the natural environment more responsive and visits more engaging, the idea of combining mobile technologies with sensors in the environment was developed to provide a means to create an inspiring place for people and nature to interact.

The lack of visitors in the Koskenniska Mill and Inn Museum located in NKBR has been recognised as another problem. According to the official statistics, there were only 300 registered visitors to the museum during summer 2008. The small number can be partly explained by the short yearly opening period of the museum (from late June to early August). With the help *Heroes of Koskenniska*, we aim to increase the visitor count and extend the period during which the visitors can learn about the museum. Although the game is not designed solely for the museum, it has some content related to the mill's history and operation, hence potentially raising learners' interest in the museum.

One of the long-term goals for NKBR is to *establish meaningful connections between various Biosphere Reserves*. These connections not only relate to visitors' learning experiences but also to research and training activities. For example, researchers working at different Biosphere Reserves could share research data and develop models and procedures that would in turn support the conservation and sustainable utilisation processes of the regions. Similarly, a learner at NKBR could interact together with a learner located in a Biosphere Reserve in South Africa, for example. To support such global networking of resources and people through pervasive technologies in Biosphere Reserves, the PLS should be flexible enough for fast deployment in varied contexts. While connections to other Biosphere Reserves are not topical at the time of writing this paper, it is an important long-term objective which influenced the decision to make the architecture viable and portable.

3. HEROES OF KOSKENNISKA

Heroes of Koskenniska is a PLS combining mobile and sensor technologies in a natural context to provide the means to raise environmental awareness among visitors of the Koskenniska Mill and Inn Museum area in NKBR. Sensor readings provide background data for the game where the player traverses the forest and museum area while performing various types of tasks. The game was developed as a joint effort of foresters, wireless technology experts, local historians and educational technologists.

The story of the game, inspired by the Finnish epic Kalevala, is based on the battle between Ukko and Hiisi. Ukko seeks heroes to battle against Hiisi and those who are brave enough are guided by Ukko through various challenges and tasks around various themes. The story interweaves concepts such as the beginning of life, the afterlife, the meaning of time, energy and animals. Currently the game content is in Finnish and English but adding other languages is possible due to the multi-language support mechanism.

The game area is divided into two parts — forest area and open area — as depicted in Figure 2. The open area encompasses the buildings as the inn, mill, smoke sauna and storage buildings. The forest area has different properties depending on the flora and fauna residing in each area. A small river runs next to the mill and flows into a nearby lake. Because of harsh weather conditions, the game is operable from May to October.

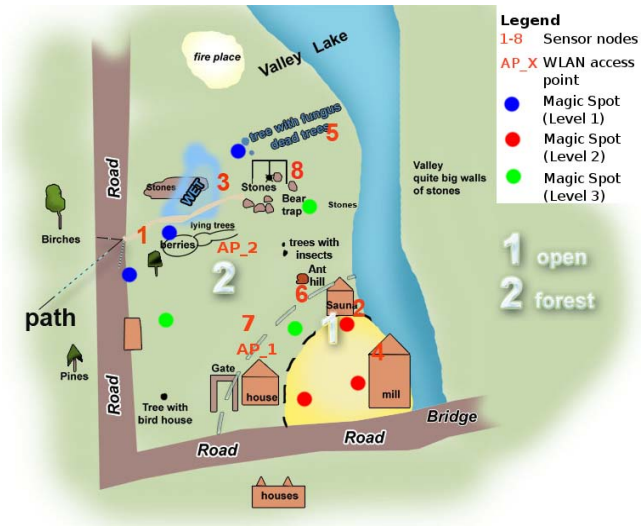
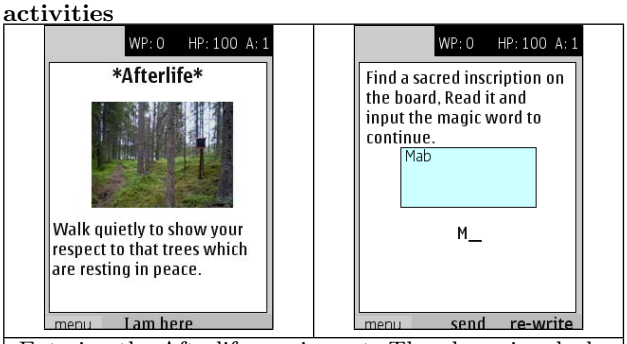


Figure 2: Map of the game featuring magic spots, sensor locations, and WLAN access points.

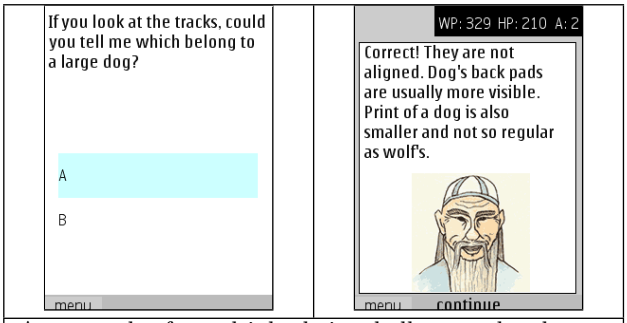
The content of Heroes of Koskenniska was designed to be viewed with Nokia N95 phones which were deemed to be sufficiently reliable and durable for the given conditions, but the content should appear similar on any J2ME phone with the same screen resolution.

The game has three levels ordered by increasing difficulty. Each level has three *magic spots*, each of which has a specific physical location and a theme. For example, the level 1 magic spots have themes *Beginning of Life*, *Details of Life*, and *Afterlife*. The player can freely choose the traversal order of magic spots within a level. The magic spots of levels 1 and 2 are clustered in the forest and open areas while the magic spots of level 3 span both areas. Each magic spot has a number of challenges which can be text-based multiple choice questions (with one or more correct answers), image-based tasks where the player must pick a correct image from several possibilities, or special *spot activities* in which the player must perform physical activities such as building a bark boat and taking a picture of it. Each challenge can have any number of screens which introduce the player to the challenge before the actual challenge screen. Sample screens of various game activities are presented in Table 1.

Table 1: Examples of Heroes of Koskenniska game activities



Entering the Afterlife magic spot. The player is asked to walk quietly so as to respect the dead trees. A text "Shhh! You are not going quietly enough!" with a sound effect is shown as a reminder after a while.



An example of a multiple choice challenge – the player is asked to distinguish a big dog's footprint from that of a wolf. At this magic spot there are animal prints carved into stone.

An example of Spot Activity – Ukko asks the player to build a boat from the forest's ingredients. Taken pictures (with players' comments) are stored for reflection.

To change the location (magic spot), the player must complete a *transfer activity* which may require them to perform

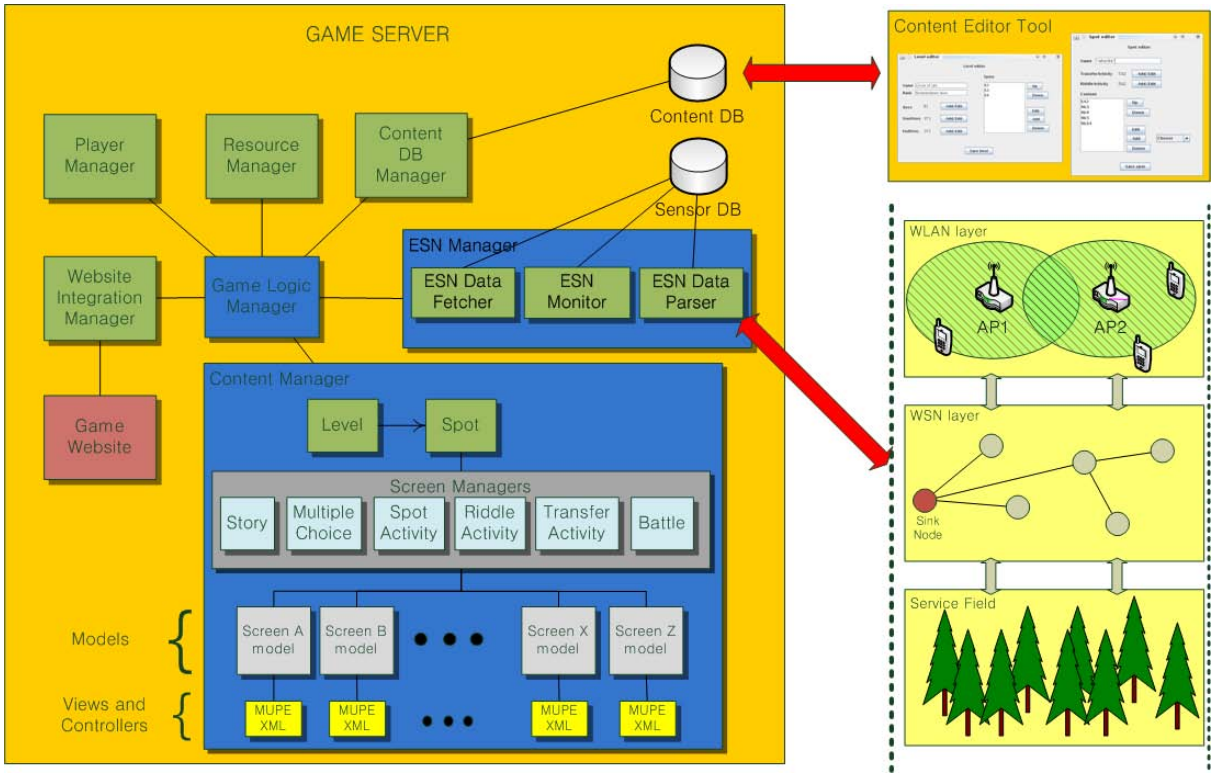


Figure 3: General architecture of the Heroes of Koskenniska

various tasks such as walk silently, find a specific object and take a picture of it, or reach the next spot as fast as possible (timer). When the player arrives at a new spot, they must solve a *riddle* which ensures the right location of the player. Riddles are presented in information boards located at magic spots. The player must find a magic word from a board and enter it into the mobile device.

At the end of each level Ukko takes the player to a battle against Hiisi. In the battle the player must connect partial phrases together to form meaningful sentences. The sentences are related to information previously acquired from the individual spots, as well as to the differences in sensor readings between the spots. Hence, the player is expected to pay attention to previous tasks as well as sensor readings in order to perform well. Contextual sensor readings can be checked at almost any moment via the game menu, and Ukko reminds the player to do so frequently.

There are two types of points in the game: health points and wisdom points. Health points (initially 100) are reduced by 10 after an incorrect answer, except in the battle against Hiisi where the penalty is 30. Completing a magic spot and a level (i.e. battle) successfully increases the player's health by 10 and 50, respectively. For each correctly solved challenge the player is awarded six wisdom points and three points extra for each additional answer when there are more than one correct answer options. Finishing a level gives the player 100 wisdom points. If the player's health reaches zero they die but they are immediately resurrected by Ukko and health is then restored back to the initial value of 100. What counts at the end is the number of wisdom points as well as attempts (lives) used in the game.

4. SCREEN-BASED ARCHITECTURE

Many PLS projects concentrate on creating systems for a single context and/or purpose only (e.g. [3], [6], [5], [13]) and viability and portability remain, if present at all, as secondary objectives. When we begun the work with Heroes of Koskenniska in February 2009, we had limited resources available. Nevertheless, a decision was made that, rather than creating hastily something that would work only for this context and purpose, we would reserve enough time for designing a system that would cater not only for other Biosphere Reserves around the world but also other learning contexts where story-based PLSs would have potential. The screen-based approach to the architectural design was considered to be a promising solution as it would allow developers and later content creators to easily create new screens and reuse existing templates. The overall architecture is presented in Figure 3. Before having a closer look at the details, we briefly review the underlying MUPE platform.

4.1 MUPE (Multi-User Publishing Environment) platform

To develop the system rapidly, we sought to use an existing software platform. We chose MUPE (Multi-User Publishing Environment)[15] as it has been used successfully in several other educational mobile game projects (e.g. [10], [13], [14]). MUPE, developed as part of the iPerG project[2], is a client-server platform with the advantage that the server pushes all client content as XML, hence eliminating the need to install new software when connecting to a new MUPE-based service. Furthermore, restarting the mobile device

[2]http://www.pervasive-gaming.org

while running the game does not reset the game status as all data is stored on the server. Client user interfaces are defined using the MUPE XML language and the server logic is written in standard Java.

MUPE supports by default text, graphics, sound, video, GPS and camera features of the mobile device. Additionally, plugins have been developed for reading smart tags such as 2D barcodes and Near Field Communication (NFC). By default MUPE does not support external databases or wireless sensor networking so those features were implemented.

4.2 Architecture description

The core idea behind the screen-based architecture (Figure 3) is to represent various combinations of screen content in a way that adding new combinations is trivial. The architecture defines a screen to consist of a *model* (Java class) and a *view* (MUPE XML sheet). *Controller* (server callbacks) is defined using XML. This separation fits well to the *Model-View-Controller* (MVC) design pattern, thus enabling flexible application development and code reuse. The model implements a content update mechanism which prepares a corresponding view (MUPE XML sheet) and returns it to the caller. User actions are processed by the controller, screen models are connected to screen managers through an interface, and screen managers in turn maintain the desired screen sequence (branching). This sequence is assigned by the content creator but the game can also let the learner choose where to go next (e.g. next magic spot). Screen managers implement an interface through which their parent components (such as magic spots) can conveniently request next or previous screens. The details of other components except the Content Manager are given in Section 5.

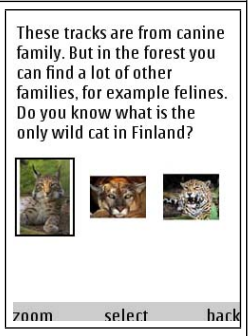
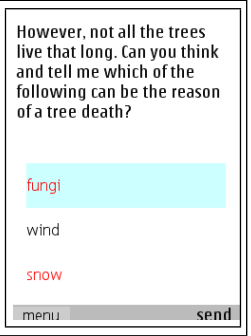
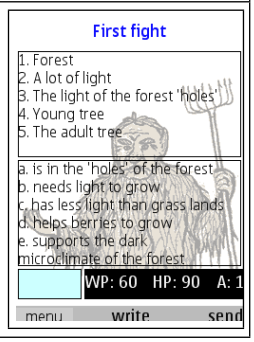
Figure 4 illustrates the flow of control between components of the game. There can be any number of levels, each having an arbitrary number of magic spots. A special story section can be embedded at the beginning or at the end of each level, and a battle section may be defined at the end of a level. Magic spots may have any number and combination of multiple choice and spot activities, each of which can in turn have any number of screens. Transfer activity can be omitted, but in the current version of the architecture riddle activity is needed as it is the method of ensuring the correct location of the player. When all levels are passed successfully the game ends.

4.3 Screen composition

Each screen can have any components allowed by the MUPE XML language including — but not limited to — text, item list, image, video, sound, links and menu. Additionally, screens can include information from data fields such as player name, sensor readings, health points, wisdom points, magic spot name and character name. Special tags can be used inside the text content of the screen so as to include information such as player's name, remaining questions or value of a specific sensor at a given location. Screens are reusable in a way that their content can be updated by a corresponding model and one model can have alternative views. Table 2 lists samples of currently implemented screens together with descriptions.

By using the 14 currently implemented screen types it is possible to create a complex and versatile game structure. Adding new screens to the architecture is simple for a developer, who must (i) create a Java class (model) to implement

Table 2: Sample screens from Heroes of Koskenniska

Screen type and typical use	Screen shot
Text-Photo Sometimes a picture can tell a thousand words. For such situations the Text-Photo screen type is optimal as it combines an explanatory excerpt with an illustrative image. Character name is used to indicate the speaker.	
Text-Multichoice-Photo The Text-Multichoice-Photo screen is useful for presenting challenges where answer options are images, thus requiring the player to explore the images closely. Each image can be zoomed to full screen size and the player must select the correct answer (image) to continue.	
Text-Photo-Multichoice-Text This screen presents a picture and several related choices of which one is correct. Typically this kind of challenge expects the player to find the answer (or a clue to it) from the presented image, which in turn may relate to a real world object.	
Text-Multichoice-Multiselect-Text This screen looks similar to Text-Multichoice-Text but the selection mechanism allows selection of multiple answers at once. This screen type can be used to make multiple choice questions more challenging than if they would have only single selection mechanism.	
Battle The Battle screen, as presented at the end of each level, allows the content developer to create pairs of statements that must be matched by the player. The high penalty value (30) encourages the player to put more effort on finding correct pairs.	

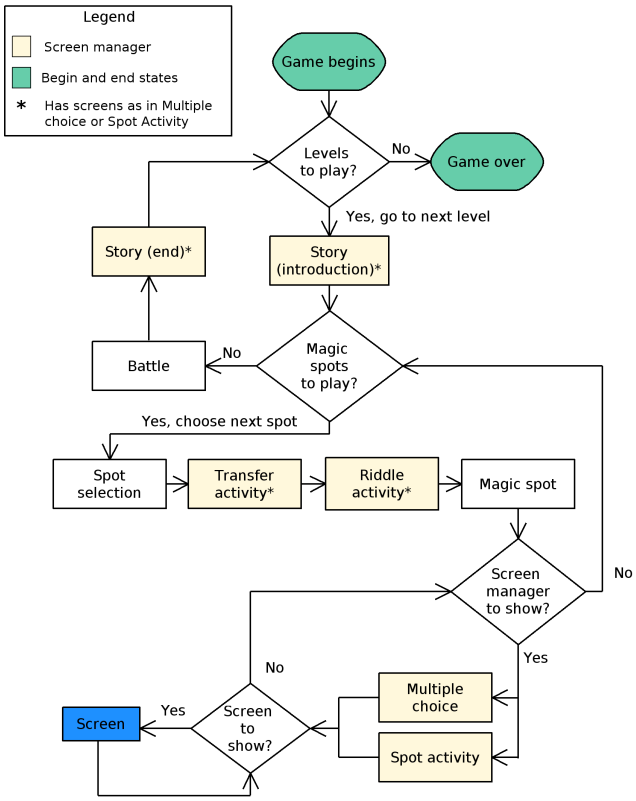


Figure 4: Flow of control in the Heroes of Koskenniska

the interface required for the screen, (ii) create a MUPE XML sheet to represent the screen layout (view) and implement any custom callbacks (controller), and (iii) add a row to the database table that lists the different screen types. Then a dedicated content editor tool can be used to add and modify screens of the newly created screen type. Ease of adding new screens and reusing existing screens makes the architecture viable.

Screens may implement other server callbacks in addition to basic next and previous screen traversal operations. For example, a *Text-Multichoice-Photo* screen, instead of simply requesting the next screen upon answer selection, requests the server to check whether the selected answer was correct.

5. IMPLEMENTATION ASPECTS

5.1 Player data and website integration

Data for the players are managed by the *Player Manager* component (Figure 3) which keeps track of the players' progress and collected information (e.g. pictures taken). The Player Manager hosts profiles of each player so as to accommodate player-specific data and preferences. It also validates the data of newly registered players and manages all the players' statuses.

When the player finishes the game or captures data (takes a picture or records sound), the *Website Integration Manager* (Figure 3) uploads the new data to the game website or stores them locally on the game server if no connection is available. The game results are published so that the players can view them later and so compete with each other if they wish. Captured elements, such as pictures, comments and sounds produced by the players, are also published for later reference and use.

5.2 Database and resources

A MySQL database was used to store the game content and readings from the wireless sensor network. The database table design follows closely the data structures of the game, including levels, magic spots, multiple choice questions, spot activities, transfer activities, riddle activities, start and end stories, and battles. Additionally, sensor readings are stored in a separate table. The *Content DB Manager* (Figure 3) handles content retrieval from the content database, and the Sensor table is used by the *Sensor Data Fetcher*, *Data Analyser* and *ESN Manager* (see below).

We also implemented a graphical content editor tool for creating and modifying game content stored in the database. The game server also includes a data loader component which is used to load the game contents to the server at startup, in order to optimise retrieval speed during play. Finally, we implemented an environmental sensor network analyser tool which monitors sensor readings and reports anomalies to the researchers by e-mail or log file.

The *Resource Manager* (Figure 3) takes care of providing appropriate resources for each service request, including language-dependent data such as user interface constants, images and game content. When the player connects to the service, they choose a language preference and this choice is used to deliver appropriate resources during the game play.

5.3 Wireless networking

Wireless networking used in Heroes of Koskenniska consists of two parts — an Environmental Sensor Network (ESN) and a Wireless Local Area Network (WLAN). Figure 2 illustrates the distribution of wireless sensor nodes and WLAN access points in the game area.

ESN is essentially a wireless sensor network (WSN) defined as a set of spatially distributed small autonomous devices (nodes) working together to solve at least one common application [16]. Each device can observe different parameters such as temperature, humidity, vehicular movement, pressure, soil makeup, noise level [1]. WSNs are used in different application areas from military to traffic to physiological monitoring. The WSN used for environmental monitoring is ESN and its components typically have the following characteristics: small size, low cost, robustness, low power, low maintenance, non-intrusive, and low pollution [4].

The ESN in Heroes of Koskenniska consists of nine networked (ZigBee) sensor nodes deployed in trees and on the ground. One of the sensor nodes is connected to the game server and acts as a sink node (id 0) for gathered sensor readings. Each sensor node is capable of sensing temperature, humidity, illumination and infra red values from the environment. The aggregation of captured data is established by a multi-hop routing mechanism where the nodes, when deployed, automatically form a routing scheme that channels all collected data to the sink node. It is also possible to send control messages from the game server to the nodes, if necessary. Each sensor node is connected to an external battery and the entire structure is protected by a plastic and (in some cases) a wooden case.

On the game server (Figure 3), the *ESN Manager* retrieves

data from the sensor network through the sink node. Retrieved sensor readings are stored in the sensor database. The *Sensor Data Fetcher* retrieves and prepares the stored sensor data for use in the game. The *Data Analyser* automatically monitors and detects anomalies in the database (such as missing sensor readings or abnormal values). Alarm thresholds can be set and all detected anomalies are logged.

As the MUPE platform requires network connectivity between server and clients, a WLAN with powerful antennas was built to cover the entire area and was chosen in order to minimise the usage costs of the system. For smooth operation, two wireless access points were bridged and distributed optimally to cover the game area. The access points were also protected against the weather.

6. ANALYSIS OF RELATED WORK

In this section we analyse existing PLSs and platforms that have similar elements to Heroes of Koskenniska, in terms of type (educational, game), content, technology or context. Articles related to the target applications were reviewed and available technical information extracted for analysis. Some applications were available for further testing but we did not perform thorough usage tests as this would require the same level of access for each target application. Table 3 summarises the comparison of the applications and Heroes of Koskenniska in terms of architectural approach (as per available information), sensor usage, viability, portability, mobile device usage, application type, data collection (by the learner), content, location awareness and network access. Viability and portability were evaluated according to the definitions given in Section 2.1 and based on the information available of the analysed systems. One reason why Heroes of Koskenniska appears to be more portable and viable than other analysed systems is because its screen-based architecture is based on the MVC division, thus allowing flexible definition and reuse of screen templates.

Ambient wood is a PLS which facilitates children's learning about scientific enquiry and hypothesis testing in a forest area [17]. The system utilises RFID and GPS technologies for determining when a learner enters a hotspot where they can pick up information about the flora and fauna of different habitats. The learner is equipped with a PDA and a probe device for measuring sunlight and humidity.

A *card-based metaphor* [17] is used to present information to learners as a deck of cards, where each card presents a piece of information. The idea of the card-based metaphor is similar to the screen-based approach presented in this paper but it is designed only for *presenting* information, thus restricting the interaction as well as knowledge construction capabilities. In Heroes of Koskenniska the content structure is more complex than a stack of ordered cards.

Moles and Mini-Moles are PC and mobile applications respectively that can be used to create and deploy mobile-driven outdoor learning activities [12]. Students can first create content on PCs with Moles which contains all needed information and knowledge questions prepared by the educator. Content is then transferred onto PDAs or mobile phones (Mini-Moles) which are subsequently taken to the field where the students answer the questions by recording observations. After returning to the classroom, recorded data is transferred to the PCs for analysis and reflection.

The system is open source, but it supports only specific types of questions and adding new types may require major changes to the source code. Prepared content cannot be dynamically modified following context changes, and content loaded on the mobile device is static. Although this is a powerful platform for implementing school field trips, the static nature of the systems renders them clumsy to be used for developing story-based PLSs such as Heroes of Koskenniska.

Environmental Detectives is another PLS for outdoor environmental education [6]. Unlike Ambient Wood, Environmental Detectives is designed as a multi-player, reality simulation game. The game player assumes the role of an environmental detective whose task is to solve a contamination problem. The game uses a mixed-reality approach by mapping real world locations to virtual game content. GPS is used for positioning players during the game play. A toolkit is included for creating content for the game in order to deploy contamination problems virtually in any location.

Environmental Detectives was implemented for one purpose only (environmental science) and while it comes with a powerful toolkit, it does not offer similar level of viability to Heroes of Koskenniska. The use of the Windows Mobile platform was also seen as a disadvantage due to the limited range of devices supported.

Taiwan Weather Inquiry-Based Learning Network (TWIN) is a system in which a wireless sensor network is used for weather monitoring and inquiry-based learning [3]. There are sixty sensor nodes (stations) deployed around Taipei, Taiwan, and each node is capable of detecting temperature, humidity, air pressure, UV radiation, rainfall rate, wind direction and wind speed at regular five minute intervals. Learning activities cover weather science study and can be accessed ubiquitously via PCs.

The idea of using wireless sensor networks for educational purposes overlaps with the concept of Heroes of Koskenniska, but rather than learning about weather science, players of Heroes of Koskenniska learn about environment and nature while sensor data are used for supporting learning activities. Furthermore, learning activities are not part of the TWIN system but the learners merely use the data provided by the system to complete tasks defined by the educators.

The aim of the **GreenSweeper** pervasive, persuasive [2], game is to promote environmental awareness in an urban environment [5]. As its name suggests, GreenSweeper borrows the game idea from the popular Mine Sweeper game where the player must clean a mine field by infering the locations of the mines based on visual cues. The game informs users about the greenness of the surrounding infrastructure so as to highlight the environmental damage and impact. The greener an area, the lower is the probability of a mine residing in that area. The main purpose of GreenSweeper is to convey to the learner the presence or absence of green areas in an urban setting. GreenSweeper uses the camera and networking features of a mobile device, but not positioning technologies. The game can be deployed to any urban environment by programming the game map as a geographical map, but it lacks a deep storyline and it supports only one type of activity (clearing mines), and does not present any educational content related to the environment.

Ubiquitous distribution of Bluetooth devices is harnessed in a clever way in the **Insectopia** [13] pervasive game where players search for virtual insects in an urban environment. Each unique Bluetooth address (i.e. every Bluetooth device that is discoverable) represents a breeding site for a type of insect which can be harvested by the player to add new

Table 3: Comparison of pervasive learning spaces

	Heroes of Koskenniska	Ambient Wood	Moles and Mini-Moles	Environmental Detectives	TWIN	Green-Sweeper	Insectopia	LieksaMyst game
Architectural approach	Screen-based	Card-based	Learner-based	Map-based	Inquiry-based	Map-based	Collection-based	Story-based
Application type	Pervasive adventure game	Augmented field trip	Mobile multimedia platform	Augmented reality game	Information inquiry system	Pervasive strategy game	Ubiquitous treasure hunt	Pervasive story-based game
Sensors	Dedicated environmental sensors	Portable probes	None	None	Dedicated environmental sensors	None	None	None
Viability	**High**	**Low**	**Average**	**Low**	**Low**	**Low**	**Low**	**Average**
Portability	**High**	**Average**	**High**	**High**	**Average**	**High**	**High**	**High**
Mobile devices	Yes	Yes	Yes	Yes	Yes, also PC	Yes	Yes	Yes
Data collection	Yes	Yes	Yes	Yes, virtual data	No	Yes	Yes, virtual data	No
Information representation	Story, various challenge types	Information on flora and fauna, questions	Multi-media questionnaires	Story, problem solving	Real time or historical weather data	Map, players' photos	Virtual insects	Story, various challenges
Context-awareness	Yes	Yes	No	Yes	No	Yes	Yes	Yes
Network access	WLAN	WLAN	None	None	Internet access required	Yes	GPRS	WLAN

insects to their collection. While the game features profiles of real insects, it does not provide much educational information on the captured insects. Rather, it is likely to teach more about the high distribution of Bluetooth devices in an urban environment than details about lives of insects. The game is designed to run continuously and new players can join at any time. Ubiquitousity of Bluetooth devices and flexibility of the underlying MUPE platform make Insectopia easy to be deployed to other contexts, but viability is low because the subject matter is very specific and cannot be adjusted.

LieksaMyst [10] is a PLS targeting at cultural history in the Pielinen Museum, Lieksa, Finland. LieksaMyst's core component is a story-based role-playing game which takes the learner back in time to meet characters who lived in the old houses and used the authentic objects for various activities. Together with these authentic (albeit fictional) characters, the learner experiences daily routines of the respective period of time.

LieksaMyst's architecture was created on top of the MUPE platform to support story-based content and activities that require the player to pay attention to the surrounding objects. Originally, we considered using LieksaMyst's architecture as the basis for Heroes of Koskenniska but it is not completely viable as it has only a limited set of available screen types and implementing new screen types is not simple. Furthermore, LieksaMyst does not support wireless sensors which are an essential part of Heroes of Koskenniska.

7. DISCUSSION

In the Section 6 we analysed several existing pervasive learning spaces and discussed their viability, portability and overall suitability for the context of Heroes of Koskenniska. We concluded that many of these systems were designed for a single context and/or purpose only. The screen-based architecture was derived to meet the viability and portability requirements of the game. Other challenges were defined as *bridging the gap between the nature and the people*, *increasing the number of visitors*, and *establishing meaningful connections among Biosphere Reserves*.

The game was designed to attract young visitors with their families to experience the natural environment through story-based game play. Knowledge about the environment is interwoven within various different tasks and an immersive storyline that places the player in the shoes of a hero. With these elements, the visitors to the Koskenniska Mill and Inn Museum area are able to learn the tacit information of the area, thus bringing them closer to the surrounding nature. Initial feedback (interviews) from multicultural adult players suggest positive experiences despite some technical problems with the network connectivity during the first tests (June 2009), as the following excerpts indicate:

- *[T]hese questions were really new to me, and about how to calculate age of a young tree, for example, that was very good.* (Male, Finland)
- *I liked the last game [the battle].* (Female, Morocco)
- *You know, it's really nice game. It takes your attention and takes your time so you can really spend your time...This game can also tell you some information about the place. It is not only playing just for fun but it's also gives you some information that you are interested in as well. Another good thing is that the game can be played in teams so you can make competitions.* (Male, Kazakhstan)
- *I didn't know that it [usnea] is growing in places with no pollution.* (Female, Namibia)

- *The connection was dead quite often and the program didn't go forward as it should have.* (Male, Finland)

The problems related to network connectivity occurred as the foliage in the forest interfered with wireless signals. After the first tests we improved the network by optimising the WLAN access points positions. This and other technical challenges as well as solutions to the challenges are planned to be presented in a subsequent publication.

The number of visitors at the Koskenniska Mill and Inn Museum area increased significantly from year 2008 to 2009; in July 2008 there were 300 registered visitors, and in July 2009 the approximate visitor count had increased fivefold[3]. While some credit of the increase can be attributed to the area's improved facilities, advertising of the game in local media may have had an effect on the increased visitor count.

The long term goal of establishing connections to other Biosphere Reserves remains still to be achieved, but now we have a screen-based architecture that can be easily ported to other locations. Throughout the project we have worked in close collaboration with the representatives from the NKBR and through their connections we aim to recontextualise the game to other Biosphere Reserves for example in South Africa and South Korea.

In the following sections the advantages and disadvantages of the screen-based architecture are summarised.

7.1 Advantages and possibilities

The greatest advantage of the screen-based architecture is the flexible creation and reuse of screen types. We developed 14 basic screen types to meet the needs of various activities and content representation in the Heroes of Koskenniska game. One can build quite a versatile game just by using these default screen types, and for creating a new screen type only three steps are required (Section 4.3). Java mobile programming (J2ME) is not needed due to the MUPE platform.

Due to the small screen size of a mobile device it is often desirable to allow navigation backwards in the story. The proposed screen-based architecture has built-in support for backwards traversal as screens are sequentially ordered by default. Branching is also enabled and is useful when the path to be followed depends on the player's action or environmental and temporal parameters.

While Heroes of Koskenniska was designed for raising environmental and cultural awareness among the visitors of the Koskenniska Mill and Inn Museum area, the same architecture can be easily adapted to other Biosphere regions by creating localised content and challenges (portability). Similarly, the architecture can be used to create games for very different purposes and contexts (viability). For example, one could write a story and challenges for a museum adventure game [10] or let the players ubiquitously explore the world of mathematics through an immersive story [8]. In fact, at the moment of writing this paper, we are in the process of creating a museum-based guide and game applications by using the screen-based architecture. Being highly viable and portable, the architecture scales well from formal education settings to informal learning arenas.

[3]Personal communication with Veli Lyytikäinen on August 17, 2009

7.2 Disadvantages and challenges

The underlying architecture was constructed upon the MUPE platform which has been designed to make mobile application development fast and easy. Despite its flexibility, having the architecture based on MUPE introduces restrictions and threats which are important to consider. Firstly, MUPE is not truly platform independent even though it should in theory support J2ME mobile devices with network access (GPRS or higher). Our tests have shown that the platform works best on Nokia devices but for example in some other manufacturers' models errors may occur. We believe this to be due to non-standard implementation of the Java Virtual Machine on the respective devices. Although this is not strictly problem of MUPE, some work is needed to establish its reliable operation on multiple platforms. Secondly, MUPE is still in the beta stage and it was archived from Nokia Beta Labs in January 2009, thus development of the platform now depends on the open source community.

One clear challenge for any mobile development project relates to the large number of different device configurations on the market. In particular, different screen sizes require extra effort by content developers as the graphics and texts of the screens should be customised for many resolutions. Currently the Heroes of Koskenniska content is made for 240x320 resolution but with the advent of touch-screen devices with larger screens, higher resolutions and touch-based operation must be considered in the future.

The content editor used for creating Heroes of Koskenniska content was built to assist researchers and is not directly suitable for educators from usability perspective. Additionally, creating new screens or modifying the models, views or controllers of the existing screens requires basic Java and XML skills. As a remedy, we are currently creating an enhanced editor tool which would allow rapid construction and utilisation of new screen types.

8. CONCLUSION

Viability and portability are essential properties of a system if it is going to be deployed in various contexts for different purposes. Previous work has not been able to satisfy both of these requirements, thus a new approach was needed, and we have presented in this paper the Heroes of Koskenniska PLS which is based on a screen-based architecture. By distinguishing model, view and controller, the screen-based architecture allows flexible definition and reuse of screen templates, and we have developed 14 screen templates which were effectively reused to accommodate game content and activities. In future projects these screen templates can already constitute quite versatile games and more screens can be easily created.

Our previous experiences with game-based PLSs (e.g. [9], [8]) have shown that a good storyline can be an important factor for going beyond mere edutainment to keep learners motivated and immersed. The story in Heroes of Koskenniska has connections to the Finnish national epic Kalevala and is tightly woven into the surrounding nature and cultural artefacts. We chose this approach to allow the players to become immersed in the game play whilst acquiring pieces of knowledge at the same time. Post-reflection might integrate these pieces together but this remains to be verified.

It was shown through discussion and observations that the game is a strong candidate to solve two of the three pre-

sented challenges of the NKBR — bridging the gap between the nature and the people, and increasing the number of visitors. The third challenge, establishing meaningful connections between Biosphere Reserves, is still work in progress.

There are still a number of challenges to be resolved and development work to be done: (i) Development of an advanced editor to allow educators to easily create customised screens; (ii) Development of other PLSs with the platform to test its viability and portability; (iii) Connecting games running at different Biosphere Reserves around the world and addressing modifications needed in the game concept and architecture; (iv) making better use of the recorded sensor readings based on the analysis of historical data; and (v) pedagogical quality should be formatively evaluated. The second challenge is already being addressed as we are currently (October 2010) developing a museum-based game which will be built on the platform described in this paper.

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