

# Critical Factors for Technology Integration in Game-Based Pervasive Learning Spaces

Teemu H. Laine, Carolina A. Islas Sedano, Mike Joy, and Erkki Sutinen

**Abstract**—Pervasive learning is a branch of mobile learning with an emphasis on context-awareness. Pervasive learning spaces (PLSs) create bridges from the real world to the virtual world, allowing the context-sensitive utilization of real-world objects and information in the learning process. Thus far, no model of technology integration for PLSs exists. We present a three-year process during which several game-based PLSs were developed. Based on the development experiences and a series of literature analyses, we present a technology integration model for game-based PLSs. The model meets the requirements of context, pedagogy, and game-design with technology. From these requirements, we derive three critical factors for technology integration in PLSs: 1) context-awareness, 2) available resources, and 3) unobtrusiveness of the technology. The model is discussed and evaluated through applying the model to the development process of *LiekkaMyst*, a game-based PLS for a museum. User perceptions and usability of our games are also evaluated. The model can be utilized by PLS designers and developers for determining which requirements must be considered when integrating technology into a PLS. While the foundations of a technology integration model are now laid, work remains to be done in identifying development and evaluation methods based on the model.

**Index Terms**—Pervasive learning, technology integration, context-awareness, pervasive learning space, game-based learning.

## 1 INTRODUCTION

TECHNOLOGY integration is a concept often used when discussing how technology is successfully brought to school environments [1]. In the context of pervasive learning spaces (PLS), technology integration can be seen as a major challenge on the road toward successful PLS design, implementation, and deployment. Just as teachers at schools, PLSs designers may also not have the needed technical knowhow to choose and integrate correct technologies in a PLS development process. A model is needed which could be used to integrate appropriate technologies to meet a variety of requirements. To our knowledge, such a model for technology integration for PLSs does not yet exist.

We invite the reader of this paper to follow a process of three years (2007-2010) during which several game-based PLSs were created. These games were created with the *Hypercontextualized Game design model* where the game is rooted in the same context in which the player is embedded [2]. During the process, we also derived a set of PLS characteristics and a technology integration model for game-based PLSs by literature reviews and artifact analyses on the developed games. The model comprises requirements from the context, pedagogy, and game design. Based on our experiences of a three-year-long process, we have recognized three critical factors that drive technology

integration in PLSs: 1) context-awareness, 2) available resources, and 3) unobtrusiveness of the technology.

The rest of the paper is organized as follows: We begin by defining the main concepts and the position of this research in Section 2. In Section 3, we state the methodology used after which a technology integration model is presented (Section 4). In Section 5, we present and analyze several game-based PLSs that were created over a three-year period. Then, there follows user feedback analysis in Section 6 which presents user evaluation results of the selected games. Finally, we conclude the findings in Section 7.

## 2 BACKGROUND

Traditional formal education [3] has been associated with locations specifically constructed for learning, such as classrooms in schools or lecture theaters in universities. Learning sessions in these environments are often teacher-driven, and student participation is limited to asking/answering questions or short conversation sessions. School homework takes place in a home environment, and after finishing their homework a child is free to play with peers. In such a scenario, knowledge transfers between schools and homes are printed in books and written down in notebooks, but is seldom constructed ubiquitously through everyday life experiences. There are exceptions where the teacher's role is that of a tutor, guiding the learners through the learning experience, where the learners actively construct the knowledge by themselves, but with regard to the cultural, social, and physical contexts [4], [5].

Informal learning has been complementing formal educational systems for some time now. In the past, instances of informal learning could include a visit to a neighboring village to exchange news or learn a new skill guided by a master. In informal learning, the context in which the learning takes place is not solely dedicated to the purpose of learning, but learning just happens to take place there, and

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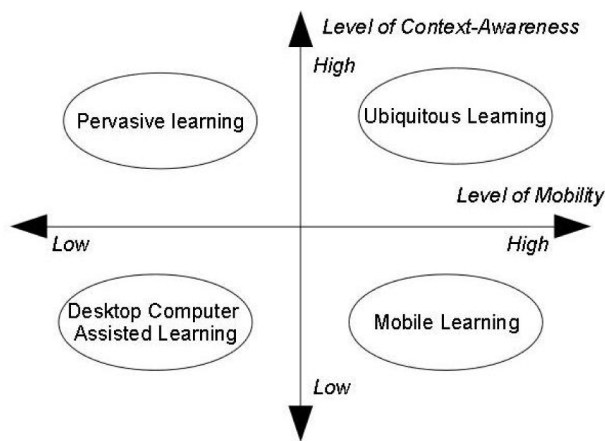


Fig. 1. Types of learning according to levels of mobility and context-awareness [9].

this is perhaps the most important difference to formal classroom-based education. The potential and the interest raised by a new, stimulating context may not only increase intrinsic motivation of the learner [6], but can also act as a catalyst for educators to implement alternative learning activities which are connected with the surrounding context.

Mobile learning, or m-learning, is a form of informal learning where the learner traverses a physical context or contexts carrying a personal mobile device which provides learning materials and activities. The key idea of m-learning is to enable anywhere anytime learning experiences that can be shared through ubiquitous network connectivity. M-learning has been popularized by the affordability of feature-rich handsets and the increasing availability of mobile-based learning applications. Recently, special branches of m-learning have also emerged, namely pervasive learning [7] and ubiquitous learning [8]. Fig. 1 illustrates the distinction between the basic four learning types in the domains of context-awareness and mobility. Context-awareness means the extent to which the system is context-aware through technologies such as sensors and smart tags, and mobility refers to the spatial mobility of the learner. While the terms pervasive and ubiquitous are often used inconsistently and interchangeably in computing, there exists a clear distinction between the two in terms of mobility; while ubiquitous learning refers to the “everywhere,” location-agnostic type of learning, pervasive learning concentrates on a limited geographical area but also concerns itself with the time, activities, and actors within the context. Despite the differences at the conceptual level, the same technologies (e.g., mobile devices, sensors, and smart tags) can be applied to both ubiquitous and pervasive learning. This paper concentrates on pervasive learning.

As stated above, pervasive learning can be considered to be an extension of m-learning with an emphasis on the roles of an intelligent environment and of the context. The physical environment is central as it provides salient resources for learning (e.g., museum objects). According to Syvänen et al. [10], a pervasive learning space, also referred to as a pervasive learning environment (PLE), is a setting in which students can become totally immersed in the learning process. They further note that pervasive computing is an immersive experience which mediates between the learner’s mental (e.g., needs, preferences, and

prior knowledge), physical (e.g., objects and other learners), and virtual (e.g., content-accessible with mobile devices and artifacts) contexts, and the intersection of these contexts is the PLS. Syukur and Loke [11] regard a PLS as a collection of mobile users, mobile services, mobile devices, and contexts and policies, while Ogata et al. [12] state that, in pervasive learning, computers can obtain information about the context of learning from the learning environment in which embedded small devices, such as sensors, pads, and badges communicate together. Common factors in these definitions include the interplay of intelligent technology and the context in which the learner is situated. The technology facilitates context-awareness which is a prerequisite for a PLS to fully utilize the richness of the context in which the learning is situated. In other words, a PLS creates a bridge from the real world to the virtual world, allowing the context-sensitive utilization of real-world objects and information in the learning process.

Games can be designed and used for a wide range of purposes, including for individual entertainment [13], as a catalyst of social interaction [14], for teaching and learning [15], as an experimental platform for new technologies and design concepts [16], and for publicity campaigns. In addition, games present a wide range of genres, independently of their digital or nondigital nature. Game-based learning, in which games are used for educational purposes, has been applied in many traditional contexts, for example, the use of nondigital games or desktop game software in language education. Most digital games with a large market share tend to have a global focus, thus disregarding the strong cultural connections that are present in many nondigital games and play (see [17] and [18]). In common with many other types of software, digital games have shifted from desktop computers to mobile devices, and the concept of *pervasive gaming* has emerged [19]. Pervasive games connect the physical environment to the virtual game world while retaining the elements of gameplay. At the same time, the culture of the game’s context must be taken into account in the game development process. Pervasive games with educational agendas facilitate deep immersion of the learner in the learning process, or in the *flow* [20]. According to Malone [21], intrinsic motivation, a component of the flow, can be facilitated in instructional environments through *challenge*, *fantasy*, and *curiosity*. Malone further argues that “games often provide particularly striking examples of highly motivating activities.” The potential of games for intrinsic motivation in learning is the reason why games are very suitable as the medium in educational technology research. In our personal experiences, games not only provide rewarding experiences for the players, but they are also highly motivating for us as researchers to work on.

### 3 METHODOLOGY

Two principal methodologies were employed for the PLS technology integration model derivation process: literature analysis (theoretical) and artifact analysis (practical). Additionally, the games we created were evaluated through various data collection techniques including pre and post-questionnaires, interviews, analyses of game data, and video recordings. The following sections describe the details of the literature review and the artifact analysis processes.

TABLE 1  
Roles of Mobile Devices in PLSs (Adapted from [22])

Role of a mobile device	Description
Data collection tool	Users collect data from the environment by using information capturing features of the device such as a camera (still and video images). Captured data can be processed further by the system or stored as a trace of learning activities, for example.
Content representation tool	In this role, mobile devices are used to view context-sensitive content provided by the system. The format of the content represented on mobile devices in the reviewed PLSs was text, image, audio or video.
Communication tool	PLS utilises mobile devices to establish communication between system users. Communication mediated by a mobile device can be either asynchronous (e.g. message forum) or synchronous (live chat), and it can take place physically (face-to-face meeting arranged through the mobile device) or virtually (through mobile device user interface).
Navigation tool	Mobile devices can be used for navigation in order to keep the user physically oriented. Navigation feature can be implemented by GPS, RFID, Bluetooth or WLAN, for example.
Note receiving tool	Announcements and notices can be delivered to the users' mobile devices. These can be for example reminders and announcements submitted by the teacher to the students, or automated information and alert messages.

### 3.1 Literature Analysis

We have performed two major literature analyses that have contributed significantly to the creation process of the technology integration model for PLSs. Papers were collected by querying popular scientific search engines such as the Google Scholar, The ACM Digital Library, and the IEEE Xplore, and then following relevant references of the papers were discovered.

An initial literature analysis focused on the state-of-the-art PLSs, the technologies used, and the roles of mobile devices in the systems [22], the latter being (Table 1) of particular interest to us as a mobile device can now be found in almost every learner's pocket. In our games, we have attempted to maximize the use of different roles for the mobile devices in order to make the interaction as rich as possible.

The papers analyzed had implicit or explicit references to the following learning models/approaches that could potentially be related to pervasive learning: Group-based learning, Individual learning, Microlearning, Authentic learning, Learning by playing, On-demand learning, Hands-on/Minds-on learning, and Problem-based learning. None of the works validated the models, and therefore, we considered this evidence inadequate in terms of suitability of the models for pervasive learning. Additionally, all of models we discovered relate to the theory of constructivism, and the contexts in which the systems were built differed from traditional classroom settings. These observations support our decision to concentrate most of our efforts on informal settings that offer possibilities for rich interaction with the physical environment.

Once the absence of a suitable learning model was confirmed, we started to investigate how a model of pervasive learning could be characterized. For this purpose, the second literature survey analyzed theoretical papers on constructivist learning applicable to museums. We focused on museums and science centers since they provide rich

environments for informal learning, and museum objects, in particular, can tell many stories to the learner. Additionally, many science centers and museums offer hands-on activities for visitors where they can, for example, construct miniature models of large objects or test scientific theories. The second literature analysis is presented in more detail in Section 4.

We also conducted several small-scale surveys which investigated, for example, the aspects of learning in museums, PLSs for specific themes such as environmental education, the use of wireless sensor technologies, and requirements of technology integration in educational settings. These secondary, but equally important, pieces of information also contributed to the creation process of the technology integration model as well as the individual games that were implemented during the three years.

### 3.2 Artifact Analysis

Artifact analysis is a methodology which has been typically used in fields such as archeology, history, and arts to research on human-made objects. The goal of artifact analysis is to reach a deeper understanding about an artifact and its usage than what would be possible by mere direct observation. We analyzed the artifacts from two perspectives [23]:

1. artifacts as designed—looking at the ways in which the explicit and implicit knowledge of the designer are exposed in artifacts, and
2. artifacts as used—looking at the way in which people have appropriated, annotated, and located artifacts in their work environment.

The *as-designed* artifact analysis was used on existing game-based PLSs to determine the key requirements which were met by the use of technology during the development processes. We considered a PLS as an artifact comprising various components such as technology, activities, pedagogy, users, content, and context, each having a unique set of requirements or restrictions. By looking at the technology integration aspects of the development processes of the artifacts, we identified categories of requirements and within them critical factors for the technology integration process. One of the games, LieksaMyst (LM), was analyzed in depth to illustrate how different requirements were met. The results of the first part of artifact analysis are presented in Section 5.

In the *as-used* artifact analysis, we evaluated usability and users' perceptions for several of our games. The evaluation results were then analyzed based on the critical factors found in the first artifact analysis. These findings are presented in Section 6.

## 4 TECHNOLOGY INTEGRATION MODEL FOR GAME-BASED PLSs

The development process of the technology integration model for PLSs started by analyzing literature on potential constructivist learning models including situated learning, authentic learning, mobile learning, contextual learning, group-based learning, exploratory learning, problem-based learning, and museum learning. The analysis was conducted by applying the principles of content analysis which makes inferences by systematically identifying specified characteristics in data (e.g., messages, articles, and logs) [24]. While

TABLE 2  
Pedagogical Requirements (Amended from [25])

User profile and perspectives
1. Multiple roles, perspectives, skill levels
2. Consideration of background, prior knowledge and experiences
3. Consideration of learning styles
Interaction and collaboration
4. Social negotiation and collaboration
5. Multimodal exploration of the environment
Ownership
6. Ownership of the learning process and outcome
7. Ownership of the technology
Authenticity and relevance
8. Authentic context
9. Authentic activities that relate to the real world
10. Compelling narrative to facilitate immersion
11. Gained experiences integrated and applied across different subject areas
12. Personal relevance
13. Unobtrusive technology
Support and assessment
14. Scaffolding techniques
15. Support for just-in-time reflection
16. Support for post-reflection
17. Immediate feedback
18. Integrated, authentic assessment (if applicable)

content analysis was originally developed for social scientists to analyze human communication (among individuals, groups, or communities), we applied it to the analysis and derivation of categories and characteristics from established properties of various learning models and theories. The process was iterative as we started from the properties of authentic learning, eliminated those properties that were clearly inappropriate, and then amended the results with findings from other theories. Periodically, we considered each of the characteristics in the context of the existing PLSs (artifacts) to ensure their meaningfulness. In the process, we aimed to recognize champions of each learning model and used their works as the basis of the analysis.

As a result of the analysis, we initially derived a set of 15 characteristics for PLSs in museums [25], which we have subsequently amended based on newly discovered evidence, thus the total amount of characteristics is 18 and they have been categorized as illustrated in Table 2. In this paper, we refer to these characteristics as *pedagogical requirements*. These requirements are immutable but not all them need to be met as we consider them more as a set of guidelines than must-have features [25]. This means that there is a certain degree of flexibility left for the technology integration process and for the game design process with regard to pedagogical requirements. From the perspective of learning, our experience has shown that unobtrusiveness of technology (13) is a critical factor in the technology integration process. This is because badly integrated technology may distract or even harm the user's learning process regardless of how well the other requirements are met. For example, if a PLS shows constant erroneous behavior due to technical problems, the user may never get a chance to enter the flow of learning, hence rendering the learning experience pedagogically useless.

Once pedagogical requirements were established, we performed artifact analyses on created PLSs in various contexts. By analyzing the PLSs' technical requirements from designers', implementors', and users' viewpoints, we formed

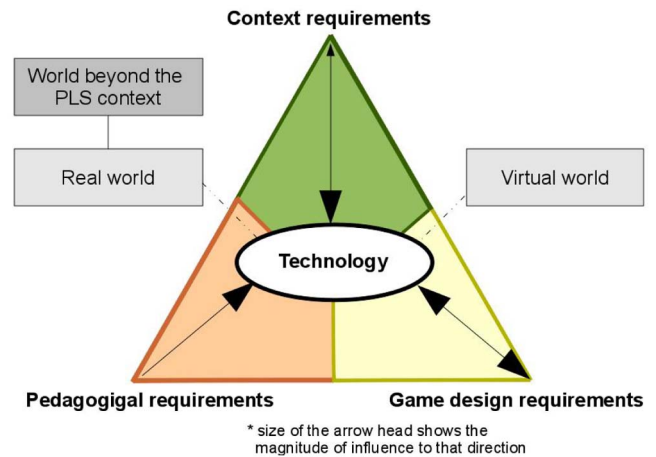


Fig. 2. Technology integration model for game-based PLSs.

the founding blocks for a technology integration model, and considered both requirements and restrictions. The artifact analysis also helped us to confirm the appropriateness of previously discovered pedagogical requirements.

Our technology integration model is illustrated in Fig. 2. The core of the model has a triangular structure in which the core is the technology (hardware and software). Each tip of the triangle represents a category of requirements that the technology can be used to meet. The requirement categories are: *context requirements*, *pedagogical requirements*, and *design requirements*, the latter referring to the concept design process (e.g., game concept design). The sizes of the arrowheads between the technology and the categories represent the magnitude of influence—the bigger the arrow, the bigger is the influence. For example, the technology may not have as big an influence on the set of context requirements as the context requirements have on the technology. As the diagram depicts, technology's role is central as it attempts to resolve a versatile set of requirements and also connects the real world to the virtual world where the digital learning content is located. The connection is done by allowing the user of the system to access the virtual world by using a set of technologies (e.g., a mobile device running appropriate client software). The connection can also be made from outside the PLS context, e.g., from the home environment through a web-based interface.

Context requirements cover various aspects that do not only require but may also restrict the use of technology. We have categorized context requirements under the following subcontexts:

- Resources—financial and human [1] (e.g., size of budget and availability of required technical skills),
- Cultural [1], [28], [29] (e.g., prohibition of flash photography and museum curator's attitude to technology),
- Technical (e.g., availability of network/electricity),
- Environmental [26], [28] (e.g., weather constraints on technology use and desirability of silence in the environment),
- Social [1], [26], [27], [28] (e.g., contextual support for collaborative learning), and
- Temporal [26] (e.g., limitation on usage time of the PLS and time available for implementation).

Context requirements are relatively static as they do not change rapidly even if the supporting technology is not available. There are cases, however, where minor changes are possible (hence the small arrow pointing at the context requirements).

For example, a museum which maintains a policy of authentic environment by not using technology in its exhibitions, may allow RFID tags to be installed on the objects if the tags are not visible to the visitors.

The game design process and the technology integration process may have much influence on each other—decisions made in the game design process may set requirements which specific technologies can meet, and the unavailability of a certain technology (e.g., specific sensor hardware) may restrict the game design process. As for context requirements, game design requirements can also be divided into subgroups.

- Context-awareness [31], [32] (e.g., level of context-awareness required),
- Dynamics [29], [30] (e.g., use of technology to support the flow of learning experience and considered case by case),
- Interaction [27], [29] (e.g., using technology to establish interactions between user, machine, and object),
- Content [29], [30] (e.g., types of media used (digital and nondigital), connection of real-world objects to the digital content).

Because each PLS is strongly based on a specific context, we consider context-awareness to be a critical factor of technology integration in the design process. At its simplest, context-awareness can be merely location-awareness, but the precision of context detection may be increased depending on the design requirements and the availability of technology. In addition to the context surrounding the learner, the learner's personal context (e.g., prior experiences and preferences) is also of great importance.

The categories of requirements derived in this section form the basis of a technology integration analysis method (based on artifact analysis) which is used in the next section to analyze various game-based PLSs.

## 5 TECHNOLOGY INTEGRATION ANALYSIS OF THE GAME-BASED PLSs

We have created game-based PLSs in various locations, including the annual SciFest science festivals [33], various kinds of museums, a South African middle school context, and a Biosphere Reserve in the Eastern corner of Finland. These games were created using the *Hypercontextualized Game design model* where the game is rooted in the same context in which the player is embedded [2]. A hypercontextualized game (HCG) is a novel game genre and while our PLSs are based on it, the HCG design model can also be used to create games that focus more on other cognitive processes such as creativity, innovation, or self-expression. During the process, the developed technology has matured to the point where it can be easily transferred between very different contexts and purposes. In the following account, we describe and analyze several of these games from the technology integration point of view. The games are categorized into three groups by their types. One of the games, LieksaMyst is

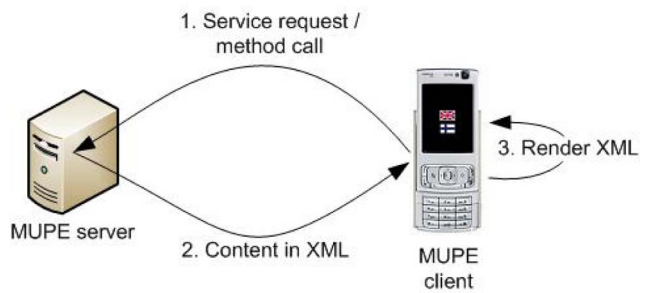


Fig. 3. MUPE communication model.

presented in detail so as to demonstrate how our technology integration model can be used to analyze a game-based PLS. Before going deeper into the games, we first describe the core technology behind all them.

### 5.1 Description of the Core Technology

Our game-based PLSs are built on customized game engines which we developed on top of Nokia's MUPE (Multiuser Publishing Environment) application platform. MUPE uses a client-server approach where the server pushes game content to clients in XML format over a network connection (Fig. 3). The advantage of this content delivery model is that if changes are made to the content, the clients do not need to be upgraded. Furthermore, the same client can be used to access several MUPE-based games and the player's status is stored on the server, i.e., the game can be resumed after a period of absence. The MUPE client is based on J2ME and should work on mobile devices that support Java MIDP 2.0. However, we have only tested it on a handful of Nokia's S60 devices (e.g., N80, N86, and N95). In order to add new features to the client, we utilized the MUPE client plugin API to add support for 2D bar codes and Near-Field Communication (NFC), and we added support for streaming multimedia to enable playback of larger media files such as narrated audio and video clips.

The scalability of the technical architecture is quite high as demonstrated by the various contexts and purposes in which different games were deployed. The MUPE server is based on several basic services, e.g., one for managing the game's main thread, one for managing client connections, one for managing media (images, sounds, and video), and so forth. Each of these services can be placed on different physical servers and they communicate over the Internet. It is also possible to create custom services, for example, to manage information acquired from specific sensor devices. Unfortunately, we do not have benchmarking results on system performance but we have successfully had up to 15 client devices connected to a single-point server simultaneously without any observable decrease of performance. So far our greatest technical challenges have been related to WLAN network connection and the stability of client devices. These problems have been remedied by widening the network coverage and investing on client devices which have sufficient resources to run the games.

### 5.2 Quiz-Based Games: SciMyst and TekMyst (TM)

SciMyst is a pervasive mobile adventure game played in 2007-2009 at the annual SciFest science festival in Joensuu, Finland. Players of SciMyst use mobile devices to explore the festival arena by solving intriguing enigmas related to the



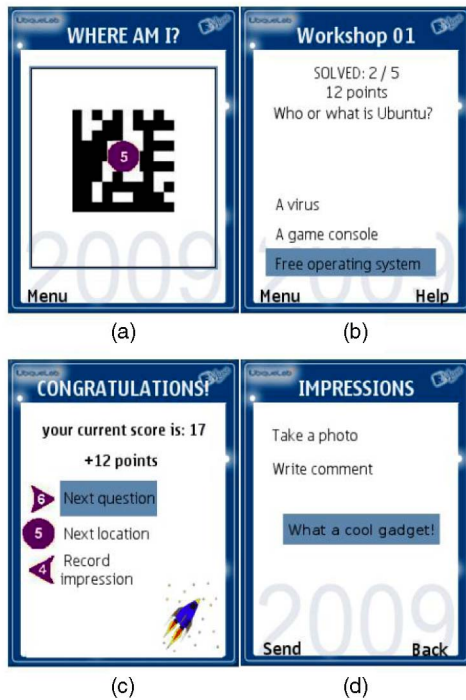


Fig. 4. SciMyst 2009 screenshots.

surrounding objects and phenomena. Each version of SciMyst has a special theme or a story, and before the game starts, the player is shown a video and/or a slide show of the story. The player can then choose to play alone or team up with friends or family members for collaborative exploration. There are several types of enigmas ranging from multiple-choice questions to take-a-picture tasks in which the player must locate a specific object based on given description and take a picture of a 2D bar code tag attached to it. An enigma relates to a specific workshop or exhibition and it is only through investigating the location that the player can find the answer. All correctly solved enigmas yield points for the player, and upon finishing the game, the points are uploaded to the game website. At the end of the game, the player has to clear the last challenge where the acquired knowledge is tested by repeating some of the game's enigmas with a countdown timer. The player is equipped with a map of the festival area where all stands are marked and areas colour-coded. If the players need help with solving an enigma, they can use context help to receive a hint, contact other players through the multiplayer help feature of the game, or interact directly with exhibitors. SciMyst utilizes 2D bar codes for detection of objects and players' locations. The game also has a website and a feature for sharing taken photographs and comments.

Fig. 4 presents screenshots of SciMyst 2009 with a space theme. In Fig. 4a, the game asks the player to determine game location by taking a picture of a 2D bar code, Fig. 4b shows a question with expandable and scrollable fields, Fig. 4c shows the positive feedback upon correct answer, and Fig. 4d illustrates the view which is shown when the player wishes to record an impression (i.e., take a picture and write a comment) to be sent to the game website.

The concept of SciMyst is located at the intersection of people, learning, technology, and playing (see Fig. 5 [34]).

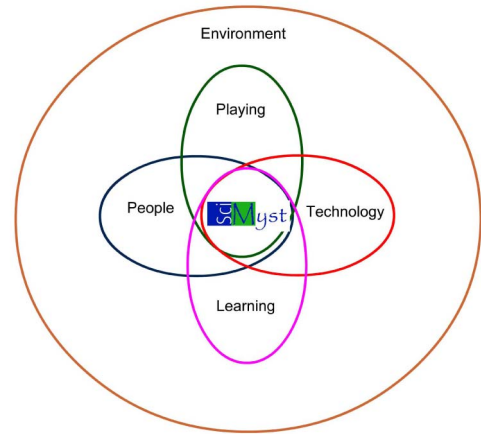


Fig. 5. Components of SciMyst [34].

The environment (the game's context) links everything together and, in case of PLSs, it is unique for each game instance. The same basic concept was utilized in all of our subsequent game releases as per their pervasive nature.

TekMyst is a game tailored from SciMyst for the Museum of Technology in Helsinki, Finland. One of the main motivations to create TekMyst was to test whether SciMyst's concept and technology could easily be ported to a different context, a space filled with machines and technological innovations. The aspects of applicability of the SciMyst concept and technology to museums are also covered in [35] which presents SciMyst's architecture together with a discussion of the concept's suitability for a museum context and an analysis of a range of potential future technologies. TekMyst was based on SciMyst's code with some small adjustments and modifications. For example, some game rules were changed, a mechanism for multiple game levels was added, and the user interface was customized. TekMyst's story involved a magical kingdom of knowledge-sharing ants and their battle against ignorance and laziness which threatened the kingdom. Whereas in SciMyst where individual visitors or small groups came to play one by one in an unscheduled manner, in TekMyst, most players were organized in several sessions as school groups.

The technology integration analysis for the SciMyst and TekMyst games revealed that the primary factors guiding the technology integration were the available budget and time, context-awareness, and game dynamics. As the resources were minimal, we used a cheap set of technologies to implement the systems quickly. Availability of resources was also guiding the game design process at some level as the design ideas were grounded in the available technology. Context-awareness was established with 2D bar codes as this approach was considered to have the best price/quality ratio. The use of bar codes also did not disturb the contexts; the Museum of Technology even encouraged bar codes due to the technological nature of the museum. The game dynamics affected mostly the design of the server software, but also contributed to the choice of specific types of mobile phones as clients. In the implementation process, we chose to create an architecture that could be reused in future games (i.e., most of our games are based on the Myst platform started with SciMyst 2007) [36].

### 5.3 Sensor-Enhanced Adventure Game: Heroes of Koskenniska

Heroes of Koskenniska (2009) is a game-based PLS where mobile and sensor technologies have been combined in a natural context to provide the means to raise environmental awareness among visitors of the Koskenniska Mill and Inn Museum area at the UNESCO North Karelia Biosphere Reserve. Sensor readings of temperature, humidity, and illumination are used as background data in the game where the player traverses the forest and museum area while solving various types of tasks. The game was developed as a joint effort of forestry experts, wireless technology experts, local historians, and educational technologists.

The story for the game is based on the epic battle between Ukko and Hiisi, characters from the Finnish epic story *Kalevala*. Ukko seeks heroes to battle against Hiisi and those who are brave enough are guided by Ukko through various challenges and tasks around different 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 straightforward due to the multilanguage support mechanism. 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, and each spot has a series of challenges for the player to solve. The challenges include 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, and special spot activities in which the player must perform physical activities such as building a bark boat and taking a picture of it. At the end of each level, the player faces Hiisi in a special battle where they must combine the knowledge gained from the level and data from the sensors.

The Heroes of Koskenniska architecture was designed from scratch as we wanted to create a more flexible design that would allow easy construction of new views and content structures—previous games had to follow a pre-defined structure, and content within the structure was modifiable only to a certain extent. Additionally, as the game utilizes a wireless sensor network, several new components had to be written to integrate the sensor technology into the PLS.

The context and purpose of Heroes of Koskenniska are significantly different than any other game-based PLSs we have created so far. Financial support received from the European Regional Development Fund granted us the possibility to include advanced wireless sensor technology, which, in turn, provided the concept designers both challenges and opportunities. A Finnish forest environment was very challenging from the viewpoint of technology integration because of tree trunks and leaves blocking wireless signals (both sensors and WLAN), humidity, temperature fluctuation, lack of electricity, vandalism, and so on. In retrospect, it took a large amount of creativity and some luck as well to be able to integrate all the technology successfully. Available technical knowhow greatly facilitated the process. Regarding context-awareness, the game is somewhat similar to LieksaMyst, where the context is detected by user-mediated code input. Instead of a code, Heroes of Koskenniska presents a riddle to the player which must be solved correctly in order to proceed. On the other

TABLE 3  
Components of the LieksaMyst PLS

Component	Description	Target group
Story-based role-playing game	Takes the visitor to a journey back in time to meet characters who tell about past lives	Anyone who enjoys interactive storytelling and is ready to use imagination to travel back in time.
Database discovery tool	Allows context-sensitive access to pictures and text located in the museum database	Adults who have visited the museum before and want to receive deeper information of houses, objects or life in the past.
RFID-based knowledge retrieval tool	Allows context-sensitive access to information based on tagged objects and exhibits, and recording of related evidence and posting comments in form of text, pictures, voice and audio. (Under construction)	Youngsters and adults who wish to explore the museum space independently and share the discovered knowledge.
Content editor	An easy-to-use content editor that has a preview functionality. Stories can be easily constructed, edited and translated.	Museum curators who are not advanced computer users.

hand, wireless sensors provide environmental data which are not available in other games. Finally, one of the requirements was to avoid over-emphasizing the presence of technology; this was accomplished by placing the ground-mounted sensor devices inside wooden boxes and attaching tree-mounted components high above the ground on branches so that they would not attract too much attention.

### 5.4 Story-Based Games: LieksaMyst (LM) and UFractions (UF)

The Pielinen Museum in Lieksa is the second largest open air museum in Finland, hosting over 70 old buildings and structures containing over 100,000 objects from different periods of time. As a living museum, it depicts how life used to be in Eastern Finland in the past. Authenticity is one of the strengths of the museum, and in order to keep the atmosphere authentic, the buildings, structures, and objects do not have visible tags and labels other than “don’t touch” signs. In order to offer an alternative experience in addition to ordinary guided tours, we developed the LieksaMyst PLS in the Pielinen Museum together with a group of museum visitors and the curators of the museum [37]. The first public tests were run in November 2008 and the results suggested that LieksaMyst was well-received, with players being able to immerse themselves in the story [25].

The concept of LieksaMyst differs from our previous game-based PLSs because it offers not only a single game but also a suite of applications which can be used by visitors with different backgrounds, interests, and learning styles. These components, their descriptions, and target groups are presented in Table 3. The story-based role-playing game is the most complex feature of the system and its concept also differs from that of SciMyst or TekMyst. Whereas SciMyst and TekMyst are quiz-based, competitive games, LieksaMyst offers a relaxed (no time limits and no competition) way to make a journey back in time to meet



Fig. 6. UFractions game screen shots. (a)-(c) Leopards let the player choose which level (time period) to play. (d)-(e) The story combines text, images, and audio. The Mother Leopard's character is friendly and caring. (f)-(g) In addition to multiple choice questions, Leopards ask the players to give answers in numbers.

and interact with fictitious characters from the past. The characters tell the player how life was like in their respective periods of time, and ask for assistance in performing various daily activities such as churning butter or warming up the house. Relevant sound effects are used to create a more authentic atmosphere. Interaction with the characters is done through a mobile device, and in addition to answering questions presented by the characters, the player must also locate specific objects in the physical environment. By embedding these objects into the story, the game teaches the player the usage of and the connections between the objects [37]. The technology used in LieksaMyst is based on the technology of previous games but some modifications were needed in order to accommodate the story-based game structure and changes in the rules. However, these modifications were made while retaining the platform's flexibility for the future game releases.

Currently, the game has two stories in two locations: a story of Anna, a friendly 40-year-old lady of the Virsuvaara house (the largest building in the museum) in 1895, and Jussi, a 30-year-old unmarried forest worker who lives in a forest camp in the 1930s and has manners comparable to lumberjacks of that time. Both characters have very different lives and activities so as to maintain the motivation toward the gameplay.

Compared to the previous quiz-like games (SciMyst and TekMyst), LieksaMyst presents deeper information about the context through a story-based approach and alternative features available to the visitors. This, together with the ability to communicate and interact with characters from the

past, as well as the connections between the objects, facilitate the immersion of the players in the authentic context. The authentic setting, coupled with an authentic (albeit fictional) story, was deemed to be one of the supporting features of the game [25]. Additionally, LieksaMyst's development effort was supported by the grants received from the National Board of Antiquities. This enabled, for example, a WLAN network to cover the essential parts of the outdoor museum area, appropriate mobile phones that could be borrowed to visitors, and hired technical knowhow to implement parts of the system. However, other technologies could not be purchased. LieksaMyst required context-awareness without disturbing the authenticity of the context or the learning experience. This was achieved by using pieces of wood with engraved numeric codes which the players then typed in using the keypads of the mobile phones. This is an example of how a compromise is sometimes needed between the technology and the context requirements.

UFractions (2009) is a story-based game built on the concept and technology of LieksaMyst. In UFractions, the player helps a mother and a cub leopard to survive by solving arithmetic fraction problems with wooden fraction sticks [38]. Screenshots of the game are presented in Fig. 6. A mobile device is used to communicate with the leopards in similar fashion in LieksaMyst, where the player communicates with the past characters. In addition to fractions, the players also learn about the lives of leopards. The major difference between UFractions and LieksaMyst is that the former is not tied to any specific context, hence context-awareness is not required from the design perspective.



Additionally, UFractions has a feature called “Find evidence” which aims to encourage the players to explore the physical surroundings to find real-world examples of fractions and share those examples online. Lack of funding prevented the implementation of new technologies to support it, but this did not significantly affect the game.

In the following sections, we analyze LieksaMyst’s requirements (pedagogical, context, and design) and how the requirements were met according to the technology integration model (see Fig. 2). As UFractions is based on LieksaMyst, many parts of this analysis also apply to it, apart from the context requirements.

#### 5.4.1 Meeting the Pedagogical Requirements

Technology alone cannot support the pedagogical requirements as they cover the entire PLS including the concept (e.g., a game). We have earlier discussed how LieksaMyst’s features support the pedagogical requirements (i.e., PLS characteristics [25]). In the following, we present only those requirements which were directly supported by the technology integration of LieksaMyst.

**Consideration of learning styles.** Different learning styles were considered by supporting various media types and multiple application types within the PLS.

**Social negotiation and collaboration.** The system is based on a client-server approach and the server is constantly aware of the status of each client. Therefore, the infrastructure to allow player-to-player communication is available, but is not currently used in any of the LieksaMyst’s applications.

**Multimodal exploration of the environment.** By using mobile technology and location-awareness it was possible to embed context-sensitive sound effects and authentic photographs in the learning experience.

**Ownership of the technology.** LieksaMyst’s client software runs on a J2ME device with appropriate computing and memory resources, hence potentially supporting a large number of visitors using their own mobile devices. In practice, as the museum borrows Nokia N95 phones to visitors, this characteristic is not fully met.

**Authentic context.** Technology integration respects the authentic context while attempting to increase the feeling of authenticity through various on-screen effects that could be related to the physical objects. Additionally, context-awareness support through numeric tags connects the game content to the authentic context.

**Unobtrusive technology.** The only technology that the learner can physically see, touch, or hear while using LieksaMyst is the mobile phone. Therefore, it is imperative that the use of the phone is as smooth and error-free as possible. We chose to use the Nokia N95 as the client device as, according to our experience, it is reliable and powerful enough for running the client software. In-game media content was rendered to be as light as possible while maintaining an acceptable quality. Another technology that may have an effect on the learning experience is the wireless network, as the game system relies on continuous communication between server and clients. Network problems during the learning process may negatively affect the learning experience. To maximize reliability of the network connection, we placed the server in the museum’s premises and connected it to a WLAN network.

#### 5.4.2 Meeting the Context Requirements

In the case of Pielinen Museum, the context of LieksaMyst, the context requirements and restrictions influenced heavily the technology integration process. The following account describes the technology integration analysis in each of the subcontexts defined in Section 4.

**Resources.** Financial resources were more ample than in case of the SciMyst series. In addition to acquiring a server and phones, a wireless local area network was constructed on museum premises. This turned out to be the most costly operation as many of the old museum buildings did not have electricity outlets and they had to be installed near to WLAN access points. Human resources from the museum were excellent in terms of content matter expertise, but technical development and server maintenance were left solely to researchers. For this reason, the system was implemented with technologies that were considered stable and which supported remote maintenance.

**Cultural.** The cultural context of the museum is characterized by the desire to maintain authenticity. For this reason, we were not allowed to use any visible stationary technologies such as touchscreens or tags, to enhance interactivity. Additionally, touching objects or photographing with flash is strictly forbidden, hence we could not use the camera feature inside the old buildings.

**Technical.** Many of the old buildings do not have electricity, and therefore, neither artificial light nor heating systems. The museum also did not have necessary server hardware or phones, but these were later acquired. The museum is within the coverage of a 3G network, but the museum decided to build a WLAN network to keep the usage costs minimal.

**Environmental.** Lack of artificial light makes most of the museum’s authentic rooms dark. Additionally, lack of heating renders the buildings cool especially at the beginning and at the end of the season (May-September). To conform to these environmental requirements, mobile devices were used as the primary interaction tools.

**Social.** Museums in general are places that support social encounters and collaborative learning [26], [27]. We chose mobile devices as a technology that can easily facilitate collaboration. Additionally, a WLAN network and client-server approach were considered to be necessary to enable player-to-player interaction. The LieksaMyst game does not yet have collaborative features, but the technology is available to support it.

**Temporal.** Outdoor exhibitions in Pielinen museum are open from May to September. In winter time, the buildings are simply too dark and cold for visitors to enjoy. The long winter break gave us enough time to integrate technologies into the design process, and after the first version of the system was finished, to develop additional features for the system as well as analyze data gathered from the usage season.

#### 5.4.3 Meeting the Design Requirements

LieksaMyst’s technology integration process and the design process supported each other, and restrictions on the use of technology set by the context requirements were also reflected in the design process.

**Context-awareness.** From a PLS designer’s perspective, more context-awareness is better than less. In case of LieksaMyst, available resources and the museum’s culture

TABLE 4

Positive Comments on TekMyst, LieksaMyst, and UFractions

What did you like about playing the game?
It was possible to get information through playing and action. It was nice to kind of discuss with Anna. (F30) [LM]
I could find out new things. Anna's intermediate comments were good. (M13) [LM]
With the help of playing it is easier to get information about history of objects and things. (M55) [LM]
Extremely fun. (F73); Interesting (M72); It was a pleasant entertainment (F19) [LM]
I could control the pace of game. I got to know how those old objects were used in the 19th century. (F21) [LM]
The game really made me go around the whole area (F16) [TM]
Gives a new point of view to the museum visit, and new energy. Highlights details that would otherwise not necessarily be paid attention to (female, 37) [TM]
I enjoy helping the ants (F13); Cute ants (F14) [TM]
The idea seemed fun. One has to take photos and it was different compared with ordinary games. (F15) [TM]
There are no normal school hour lectures and you were allowed to play with the hands (M12) [TM]
The phone, the impulse to get to know the exposition given by the phone. Fun when I could give comments to the photos. (F39) [TM]
Its more nice to learn maths by playing a game unlike learning it in class (F15) [UF]
Helping the mother and the cub leopard (M15); I enjoyed all the questions and helping the leopards (F13) [UF]
I didn't enjoy playing with leopards, but solving the problem[s] was interesting (F15) [UF]
I enjoyed playing with the cuisenaire rods and solving the problems. It was also interesting to see how the leopards grow and how they take care of themselves. (F13) [UF]
I liked the way they explained the questions and how they wanted us to find the answers. (M13) [UF]

restricted the use of advanced technology to enable a high level of context-awareness. As the game design required a basic level of context-awareness, we combined authentic-looking wooden tags with manual code input on the mobile phone. By assigning a unique code to each game object, the server is able to determine the user's location when a code is entered. In addition to location, the server is also aware of the current time and other players present in the same room.

**Dynamics.** The availability of object-based context-awareness gave the design process an opportunity to use physical objects as part of the gameplay and to create connections between the objects. On the other hand, the design process requested the use of rich multimedia to support player immersion, hence the system was built to support flexible use of text, images, and sound.

**Interaction.** Connectivity between the hardware components of the system was established over a WLAN connection so as to provide a means for client-to-client as well as client-to-server interactions. The game design process promoted the interaction between a player and a virtual character. This was accomplished by a dialog on a mobile device screen, which was controlled with the mobile device keys and connected to the real-world objects through wooden tags with codes (see context-awareness above).

**Content.** One of the first requirements of the design process was that the game content should be created in such a format that new content could easily be added later. Following this requirement, LieksaMyst's game server was designed to support the easy addition of new content in the given XML format, including various media types (text, images, and sound). Later, a graphical editor

TABLE 5

Negative Comments on TekMyst, LieksaMyst, and UFractions

What did you dislike about playing the game?
It was dark and cold; I couldn't touch objects. I didn't appreciate repeats and sentences like "you are smart". I would appreciate more answer yes/no and explanation how something works. (F21) [LM]
Lack of image zooming (M62) [LM]
Most of conversations are just text. I think sometimes it should be better [if] the text will be explained on voice. (M29) [LM]
Difficult to see the numbers [next to objects], for me a little bit too much story telling (M26) [LM]
Character buttons are too small so I made errors unintentionally (F75) [LM]
The phone crash sometimes (F13); Places are not found, sometimes the game freezes (M13) [TM]
Some were hard questions (F12); I consider some questions hard (M13); Some questions were unnecessarily hard (F13) [TM]
I would have wanted still to play a bit longer (F13) [TM]
It is hard to concentrate in the questions when the children are with you (F34) [TM]
For me the most difficult was taking good photos (F37) [TM]
You can't skip the questions. Everything has to be correct before you can advance. The questions were strange (F15) [TM]
Going hunting was difficult (F14); I didn't like the fractions (F15); I dislike when I have to divide so I have to find the right answer (F15) [UF]
I dislike the dangers that the Leopards face and how they mark their territory (F13); Dislike the hyenas eating the cub (M14) [UF]
Why they like to kill? (M14) [UF]
It was just perfect (M14); Nothing, I like everything about them (F14); There is nothing that I dislike and nothing was difficult. The game just got us thinking. (F14) [UF]
Had to first grasp the concept of the bars (M47); Connection between mobile game + cuisenaire sticks (M20) [UF]

was constructed to fulfill the requirement for easy content management. Another requirement was to support multiple languages, and currently LieksaMyst has Finnish and English content ready.

## 6 USER FEEDBACK ANALYSIS OF THE GAME-BASED PLSs

The game-based PLSs presented in this paper have been evaluated mostly by using a questionnaire-based evaluation on youngsters, but also some adults and senior citizens have participated in test events. All questionnaires comprised pregame and postgame parts. The pregame part was aimed to collect demographics data as well as data on attitudes and previous experiences with games and technology. The postgame part collected players' opinions, for example, on their learning experiences, game content, usage of media, usability, the context itself (e.g., museum), and motivators. In this section, we present likes and dislikes of the players on TekMyst, LieksaMyst, and UFractions, and usability perceptions on LieksaMyst and SciMyst 2008. The numbers of test participants were 40 (SciMyst), 129 (TekMyst), 49 (LieksaMyst), and 125 (UFractions). Our view is that in technology-enhanced learning environments such as PLSs, usability is one way to measure the success of technology integration and to identify particularly obtrusive aspects of the technology.

A representative collection of likes and dislikes on TekMyst, LieksaMyst, and UFractions is shown in Tables 4 and 5. The following positive aspects were reported by several players: getting information/exploring area, interaction with virtual characters, having a different experience,

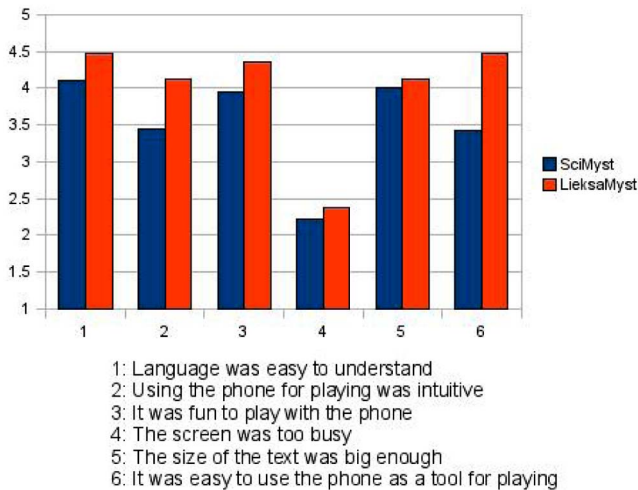


Fig. 7. Usability of LieksaMyst and SciMyst 2008.

solving problems, entertainment, and story. On the other hand, the following negative aspects were commonly reported: small screen size (small images and text), small buttons of the device, difficult tasks, phone crashing/network problems, and the story. It was interesting to note that the story was perceived both as a positive and a negative aspect by the players. For example, some South African UFractions players did not like the cruelty of the predators against the leopards. On the other hand, the story was very much appreciated by many South African players as they seemed to be deeply immersed in the gameplay. Similarly, while many players reported “solving problems” as a positive aspect of the game, others regarded some of the tasks too difficult. This indicates the need for adjusting the content according to a player’s background and skills. Technical and usability problems with phones can be reduced by choosing a client device that has larger buttons, larger screen, and more resources (RAM and CPU), and a network that covers well the entire game area.

To further measure usability of the games, we presented the players with a series of statements regarding language, use of the phone, and screen content. Results for LieksaMyst (LM) and SciMyst 2008 (SM) are shown in Fig. 7 which presents average answers on scale 5—Strongly Agree (SA), 4—Agree (A), 3—No Opinion (NO), 2—Disagree (D), and 1—Strongly Disagree (SD). Usability was generally considered good in both games, but there were some differences between the two games which we would like to point out. First, understanding the language was not easy for a few players of SciMyst (15 percent), possibly because the SciFest 2008 festival hosted a number of foreign youngsters who played the English version of the game but did not have English as their native language. Second, the phone was not deemed intuitive by a higher number of SciMyst players than in case of LieksaMyst. One reason for this could be that in the SciMyst test, the majority of phones were Nokia N80s which have arguably not as high usability and fault tolerance as N95 phones which were used more in LieksaMyst. Another possible reason could be that navigation of the game was slightly more complex in SciMyst due to the use of 2D bar codes which several players reported

TABLE 6  
Usability Suggestions and Their Relations to Critical Factors

Suggestion	Rationale	Critical factors
Select a client device that is comfortable to use	This involves a financial investment and has a direct effect on usability and thereby unobtrusiveness of the technology.	Resources, Unobtrusive technology
Use simple and clear user interface	An unclear user interface can disturb usability and thereby the learning experience.	Unobtrusive technology
Ensure that the network operates seamlessly	This involves financial as well as human capital investment. Problems in network connection affect negatively to the learning experience.	Resources, Unobtrusive technology
Make sure that tasks and story are appropriate for the context (also personal context)	Highly context-aware PLS is aware of the learner’s experiences and preferences, as well as of the context surrounding the learner. Preparing multiple sets of learning materials requires money and time.	Context-awareness, Resources
Support the native language of the player	Highly context-aware PLS is aware of the learner’s personal context. Preparing multiple sets of learning materials requires money and time.	Context-awareness, Resources
Involve the environment	The PLS should be aware of the physical objects in the context, and connection between these objects and the virtual game world should be unobtrusive to the learner. Creating these connections may cause additional costs (e.g. RFID technology).	Context-awareness, Resources, Unobtrusive technology

having trouble with. Third, the screen was considered calm in general, but in LieksaMyst, there were slightly more people who considered the screen busy. We suspect that this could be due to a richer use of larger amounts of text, multimedia, and cartoon characters in the screen layout of LieksaMyst. Fourth, text was reported to be of sufficient size by most of the players, but in SciMyst, there were slightly more of those players (13 percent) who wished to have larger text size. Again, we believe that the cause for this could have been the use of N80 phones which have a higher screen resolution but smaller physical screen size than N95. Finally, several SciMyst players (35 percent) considered the phone a difficult tool for playing, confirming the intuitiveness result above.

Based on these results, we have derived a set of suggestions for aspects that are important for the general usability of PLSs similar to our games. Table 6 describes these suggestions together with their relations to three critical factors: Context-awareness, Resources, and Unobtrusive technology.

## 7 CONCLUSIONS

Pervasive learning spaces are modern learning environments where mobile technology and context-awareness have been harnessed to provide context-sensitive materials and learning challenges that have deep relevance to the surrounding environment. We concluded that a model is needed which could be used to integrate appropriate technologies to meet a variety of requirements in the PLS

development process. Such a model would be useful not only in designing PLSs, but also for evaluating the user experiences within the PLS.

We presented a process of three years during which various game-based PLSs were created with the Hypercontextualized Game design model. The game was chosen as the medium to support learning in informal settings. The games presented range from competitive, quiz-based treasure hunt games to more relaxed story-based role-playing games. All games utilize the same basic technology whose flexibility makes it possible for us to develop new games with relatively few resources.

From the knowledge gathered through a literature analysis on a group of existing constructivist learning models, we established a set of characteristics for PLSs, which, together with an artifact analysis of the created PLSs, contribute to the emergence of what we refer to as a technology integration model for game-based PLS. Its core consists of technology and various requirements from context, pedagogy, and game design. These requirements are divided into subcategories which, in turn, are supported by the literature. The technology integration process attempts to integrate a set of technologies to meet the various requirements and restrictions. Technology has also other purposes than satisfying the aforementioned requirements, e.g., to create a bridge between the real world and the virtual world.

Based on our experiences and the supporting literature, we established three critical factors that drive the technology integration process: 1) context-awareness, 2) available resources, and 3) unobtrusiveness of the technology. Context-awareness is a key feature of PLSs and the extent to which it is supported guides the technology integration process as well as other aspects of the design process (e.g., interaction). Availability of resources in a context may set restrictions on technology integration which, in turn, may affect the PLS design process. Finally, integrated technology should be unobtrusive; this is a core element for technology integration because the learner's immersion, the set pedagogical goals, and the motivational aspects of the game would all suffer should the technology attract too much unwanted attention.

We evaluated the model by analyzing the technology integration process of LieksaMyst and discussing how the requirements were met by the use of technology (Section 5). Additionally, a subset of our game-based PLSs was evaluated by discussing user perceptions of three of the games, and usability ratings for two games. Based on these data, we suggested six aspects that are important for the general usability of game-based PLSs, and related the critical factors to these aspects. Our view is that in technology-enhanced learning environments such as PLSs, usability is one way to measure the success of technology integration and to identify particularly obtrusive aspects of the technology.

The technology integration model and its critical factors were derived primarily for game-based PLSs, but they may well be applicable to other application types in informal as well as formal learning environments. This is because the model pays close attention to context and design requirements without restricting them to any specific focus area. Future user base of the model consists

of PLS designers and implementors who work together with other stakeholders throughout the PLS development and evaluation processes.

Although three very interesting and fruitful years have passed, our work has just started. Future work involves refining the model to the point where we can establish a set of criteria for evaluating each of its components on existing game-based PLSs. Evaluations should be done on third-party PLSs so as to measure the generalizability of the model. Furthermore, evaluation methods for the model are to be developed. While this all relates to the theoretical part of the work, we will continue practical experiments with our existing game-based PLSs as well as looking for opportunities to create new games in new areas. During this process, we seek to develop the technology to a state where it can be conveniently ported to various contexts and for different purposes with minimal work effort.

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## REFERENCES

- [1] P. Ertmer, "Addressing First- and Second-Order Barriers to Change: Strategies for Technology Integration," *Educational Technology Research and Development*, vol. 47, no. 4, pp. 47-61, 1999.
- [2] C. Islas Sedano, E. Sutinen, J. Pawlowski, and T.H. Laine, "Games Rooted in the Player's Context: An Introduction to Hypercontextualized Game Design," to be published.
- [3] A. Kohn, *The Schools Our Children Deserve: Moving Beyond Traditional Classrooms and "Tougher Standards."* Houghton Mifflin, 2000.
- [4] S. Papert and I. Harel, *Constructionism*. Ablex, 1991.
- [5] L.S. Vygotsky, *Mind and Society: The Development of Higher Psychological Processes*. Harvard Univ. Press, 1978.
- [6] M. Csikszentmihalyi and K. Hermanson, "Intrinsic Motivation in Museums: Why Does One Want to Learn?" *Public Institutions for Personal Learning: Establishing a Research Agenda*, J. Falk and L.D. Dierking, eds., pp. 67-77, Am. Assoc. of Museums, 1995.
- [7] J. Hundebol and N.H. Helms, "Pervasive Learning Environments," *Proc. Soc. for Information Technology and Teacher Education Int'l Conf.*, pp. 2226-2231, 2006.
- [8] H. Ogata and Y. Yano, "Context-Aware Support for Computer-Supported Ubiquitous Learning," *Proc. IEEE CS Int'l Workshop Wireless and Mobile Technologies in Education*, pp. 27-34, 2004.
- [9] K. Lyytinen and Y. Yoo, "Issues and Challenges in Ubiquitous Computing," *Comm. ACM*, vol. 45, no. 12, pp. 62-65, 2002.
- [10] A. Syv nen, R. Beale, M. Sharples, M. Ahonen, and M. Lonsdale, "Supporting Pervasive Learning Environments: Adaptability and Context Awareness in Mobile Learning," *Proc. IEEE Int'l Workshop Wireless and Mobile Technologies in Education*, pp. 251-253, 2005.
- [11] E. Syukur and S.W. Loke, "MHS Learning Services for Pervasive Campus Environment," *Proc. Fifth Int'l Workshop Pervasive E-Learning*, pp. 204-210, 2007.
- [12] H. Ogata, C. Yin, and Y. Yano, "JAMIOLAS: Supporting Japanese Mimicry and Onomatopoeia Learning with Sensors," *Proc. Fourth IEEE Int'l Workshop Wireless, Mobile and Ubiquitous Technologies in Education*, pp. 111-115, 2006.



- [13] P. Holleis, M. Kranz, A. Winter, and A. Schmidt, "Playing with the Real World," *Proc. Int'l Workshop Pervasive Gaming Applications (PerGames '05)*, pp. 43-50, 2005.
- [14] V. Paelke and C. Reimann, "Vision-Based Interaction—A First Glance at Placing MR Games in the Real-World Around Us," *Proc. Int'l Workshop Pervasive Gaming Applications (PerGames '05)*, pp. 92-97, 2005.
- [15] S. Alessi and S.R. Trollip, *Multimedia for Learning Methods and Development*, third ed. Allyn and Bacon, 2000.
- [16] M. Chalmers, L. Barkhuus, M. Bell, B. Brown, M. Hall, S. Sherwood, and P. Tennent, "Gaming on the Edge: Seams in Pervasive Games," *Proc. Int'l Workshop Pervasive Gaming Applications (PerGames '05)*, pp. 11-18, 2005.
- [17] C. Islas Sedano and C. Kampf, "Designing Games as a Vehicle for Passing on Cultural Knowledge: A Case Study of Finnish Seniors in the Digital Age," *Proc. Sixth Int'l Conf. Cultural Attitudes Towards Technology and Comm.*, 2008.
- [18] J. Huizinga, *Homo Ludens: A Study of the Play-Element in Culture*. Beacon Press, 1955.
- [19] IPerG Project Website, <http://iperg.sics.se/index.php>, 2010.
- [20] M. Csikszentmihalyi, *Finding Flow: The Psychology of Engagement with Everyday Life*. Basic Books, 1998.
- [21] T.W. Malone, "Toward a Theory of Intrinsically Motivating Instruction," *Cognitive Science*, vol. 5, no. 4, pp. 333-369, 1981.
- [22] T.H. Laine and M. Joy, "Survey on Context-Aware Pervasive Learning Environments," *Int'l J. Interactive Mobile Learning (I-JIM)*, vol. 3, no. 1, 2008.
- [23] D. Ramduny-Ellis, A. Dix, P. Rayson, V. Onditi, I. Sommerville, and J. Ransom, "Artefacts as Designed, Artefacts as Used: Resources for Uncovering Activity Dynamics," *Cognition, Technology and Work*, vol. 7, no. 2, pp. 76-87, 2005.
- [24] O. Holsti, *Content Analysis for the Social Sciences and Humanities*. Addison-Wesley, 1969.
- [25] T.H. Laine, C. Islas Sedano, M. Vinni, and M. Joy, "Characteristics of Pervasive Learning Environments in Museum Contexts," *Proc. World Conf. Mobile and Contextual Learning (MLearn '09)*, pp. 26-34, 2009.
- [26] R.E. Grinter, P.M. Aoki, A. Hurst, M.H. Szymanski, J.D. Thornton, and A. Woodruff, "Revisiting the Visit: Understanding How Technology Can Shape the Museum Visit," *Proc. ACM Conf. Computer Supported Cooperative Work*, pp. 146-155, 2002.
- [27] L. Bannon, S. Benford, J. Bowers, and C. Heath, "Hybrid Design Creates Innovative Museum Experiences," *Comm. ACM*, vol. 48, no. 3, pp. 62-65, 2005.
- [28] J.H. Falk and L.D. Dierking, *Learning from Museums: Visitor Experiences and the Making of Meaning*. AltaMira, 2000.
- [29] L. Ciolfi and L. Bannon, "Designing Interactive Museum Exhibits: Enhancing Visitor Curiosity through Augmented Artefacts," *Proc. European Conf. Cognitive Ergonomics*, pp. 62-65, 2002.
- [30] G. Vavoula, M. Sharples, P. Lonsdale, P. Rudman, and J. Meek, "Learning Bridges: A Role for Mobile Technologies in Education," *Educational Technology Magazine: The Magazine for Managers of Change in Education*, vol. 47, no. 3, pp. 33-37, 2007.
- [31] A. Dix, T. Rodden, N. Davies, J. Trevor, A. Friday, and K. Palfreyman, "Exploiting Space and Location as a Design Framework for Interactive Mobile Systems," *ACM Trans. Computer-Human Interaction*, vol. 7, no. 3, pp. 285-321, 2000.
- [32] D. Raptis, N. Tselios, and N. Avouris, "Context-Based Design of Mobile Applications for Museums: A Survey of Existing Practices," *Proc. Seventh Int'l Conf. Human Computer Interaction with Mobile Devices and Services*, pp. 153-160, 2005.
- [33] Univ. of Eastern Finland, "SciFest Home Page," <http://www.scifest.fi/home>, 2010.
- [34] C. Islas Sedano, T.H. Laine, M. Vinni, and E. Sutinen, "Where Is the Answer?—The Importance of Curiosity in Pervasive Mobile Games," *Proc. FuturePlay Conf.*, pp. 46-53, 2007.
- [35] T.H. Laine, C. Islas Sedano, M. Vinni, and E. Sutinen, "Engagement, Motivation and Inspiration: The SciMyst Framework in Museums," *Proc. Fourth Int'l Conf. New Exploratory Technologies*, 2007.
- [36] T.H. Laine, M. Vinni, C. Islas Sedano, and M. Joy, "On Designing a Pervasive Mobile Learning Platform," *ALT-J: Research in Learning Technology*, vol. 18, no. 1, pp. 3-17, 2010.
- [37] T.H. Laine, C. Islas Sedano, M. Vinni, and E. Sutinen, "Uncovering the Richness of an Authentic Living Museum through Pervasive Learning Environment," *Proc. Ninth IEEE Intl. Conf. Advanced Learning Technologies*, pp. 655-657, 2009.
- [38] E. Turtiainen, S. Blignaut, C. Els, T.H. Laine, and E. Sutinen, "Story-Based UFractions Mobile Game in South Africa: Contextualization Process and Multidimensional Playing Experiences," *Proc. Second Workshop Story Telling and Educational Games*, 2009.
- [39] T.H. Laine, C. Islas Sedano, E. Sutinen, K.-T. Yong, H.-J. Woo, C.-W. Lee, and T. Jaakkola, "Heroes of Koskenniska and Self: Application of Body and Exercise Monitoring to a Pervasive Educational Game," *Proc. Third Int'l Symp. Learning and Teaching of Motor Skills*, Poster Session, 2009.



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