SMART TAGGING TECHNOLOGIES IN PERVASIVE LEARNING ENVIRONMENTS

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ABSTRACT

Smart tagging represents a way of marking an object with a tag carrying an encoded message which can be decoded with an appropriate reader device. As such comparison study of RFID and 2D barcode technologies does not exist, a pervasive mobile learning environment for vocabulary/memory training (MemGame) was developed for 2D barcode and RFID modes and then tested. Participants expected RFID to be faster and more convenient to use than 2D barcode and these views only strengthened after the test. For everyday life scenarios RFID was more preferred. While RFID is clearly preferred smart tagging technology, cheap price and wide availability of reader devices makes 2D barcode still a good alternative. These results might be useful not only for further pervasive learning environment development but also for mobile application development in general where RFID and/or 2D barcodes are utilized. Concrete outcomes of this study are an NFC plugin for MUPE platform and the MemGame.

KEYWORDS

RFID, 2D barcode, smart tags, e-learning, pervasive learning environment.

1. INTRODUCTION

Smart tagging represents a way of marking an object with a tag carrying an encoded message which can be decoded with an appropriate reader device. These tags can then be used in context-aware applications to detect user's context as he/she interacts with the tags. As one of the latest smart tagging technologies, Radio Frequency Identification (*RFID*) technology has been developed for many years and it has now become a serious challenger for the traditional barcode technology. Nevertheless, the latter has obtained its more advanced type: a two dimensional barcode (*2D barcode*). Both RFID and 2D barcodes have been used with mobile technologies, including ubiquitous and pervasive computing. Pervasive mobile learning applications such as SciMyst (Islas-Sedano *et al*, 2007) and JAMIOLAS (Ogata *et al*, 2006) are good examples of educational mobile learning applications utilizing 2D barcodes and RFID, respectively. Despite the efforts invested in building learning systems using either one of these technologies, there is lack of usability studies of them in the educational domain.

This paper is constructed according to different research methods employed in this study. It starts with a literature review where RFID and 2D barcode technologies were analyzed. Special attention was put on comparing features of the technologies. The next stage is a design based research in which an NFC plugin and a MemGame mobile application were developed for experiment purposes. In the last phase, research experiments were conducted. Feedback from users was collected with a questionnaire upon a usability study.

1.1 RFID

Radio Frequency Identification is a technology that allows a small radio device attached to an item to carry an identity for that item (Glover and Bhatt, 2006). Items may for example be goods, pets or people. An RFID system includes at least a tag (transponder), a reader (interrogator with an antenna) and a data processing environment. An RFID enabled mobile phone may function as a processing unit. In this case both the reader and processing unit are embedded in one handheld device.

The function of an RFID system may be described as follows. Reader's antenna emits radio waves and once a tag is within the working range, it receives the radio signal. Then the tag responds back with its own data message. The reader decodes the received data from the tag and this data is passed to a data processing environment for further processing (Figure 1).

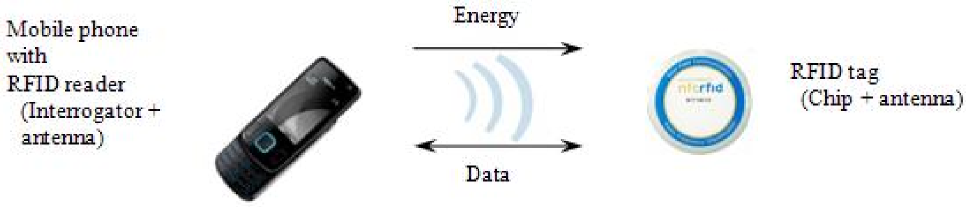

Figure 1. Mobile RFID system

RFID tag has usually an integrated circuit or chip and an antenna. These components enable tag to respond and emit radio signals. Tags may be categorized by power type (*active* or *passive*), memory capacity, working mode (*read only* or *read and write*), and frequency range.

RFID tags as well as readers may operate in a range of frequencies from 125 kHz to 5.8 GHz depending on application. RFID frequencies may be divided into four general bands (Table 1).

Table 1. RFID frequency spectrum comparison

	Low Frequency (LF)	**High Frequency (HF)**	**Ultra High Frequency (UHF)**	**Microwave**
Frequency	125-134 kHz	13.56 MHz	433, 860-930 MHz	2.4, 5.8 GHz
Tag expense	High	High, Medium	Medium	High
Reader cost	Low	Medium	High, Medium	High
Work range (max.)	~30 cm	~1m	~30 meters (active)	More than 100 m (>300 m active)
Data rate	Low	Medium	High	High
Interference	Low	Low	Medium	High
Advantages	Low environment absorption	Available worldwide	Perfect for medium range applications	Wide access range
Common applications	Animal ID, security, engine immobilizers	Security, item tracking, ticketing	Container, truck tracking	Access control, industry

Reader (*interrogator*, transceiver) is a part of the RFID system for bidirectional communication with RFID tags and other RFID enabled devices. Reader's purpose is to put or retrieve data from RFID tags. Reader may have an on-board or an external antenna depending on application, and it is powering passive and semi-passive RFID tags by transmitting radio waves with its antenna.

Near Field Communication (NFC) is a short-range wireless connectivity technology that emerged from the combination of existing radio identification and interconnection technologies. It is an extension of the ISO14443 contactless card standard. Combining a smartcard and a reader into one device allows an NFC enabled phone to act as a reader or a tag, depending on the selected operating mode. NFC supports HF operating frequency (13.56 MHz) and data transfer rates up to 424 Kilobits per second (NFC forum, 2011).

1.2 2D barcodes

Most of the people have seen barcodes printed on goods and food that they buy in stores. UPC and EAN codes are mostly used for labeling such products, while the number of different barcode types is over three hundred. Since barcodes are cheap to produce and machine recognizable, they are very popular in different areas of industry. Usually barcode labels merely contain a unique identifier and therefore barcode's small data storage capacity is enough. This unique identifier is used to access additional product information like name or price stored in a database.

2D barcode is an extension of an ordinary (1D) barcode and as it uses additional dimension, it is capable of storing more data. 2D barcodes use a visual representation of binary code: white module represents zero and black module represents one, or vice versa. Nowadays there are more than 20 different types of 2D barcodes. Typical examples of 2D barcode technologies are QR Code, PDF417, Semacode and MaxiCode.

Working with 2D barcodes requires special hardware and software. In case of special reader devices, the software is already embedded in the device. Mobile phones may read 2D barcodes if they have an onboard camera and appropriate decoding software installed. On some models of mobile phones such software is preinstalled and phone is ready to work with 2D barcodes (e.g. Nokia N95, E71, E90) (Nokia, 2011).

Exact decoding process depends on the type of tag being encoded. Let us consider decoding a URL embedded to a Semacode with a mobile phone having a Semacode decoder software installed on it. When a mobile phone user points camera to a 2D barcode and presses a button, the mobile phone camera snaps a picture and the software recognizes the 2D barcode on it. As a result of decoding the 2D barcode, the software outputs the embedded URL which is opened automatically by a mobile browser.

1.3 Usage of smart tagging technologies

The first applied use of RFID-like technology dates back to World War II time, when British Royal Air Force used it for friend or foe aviation identification (Wikipedia RFID, 2011). RFID technology is now used in a variety of applications where tracking of objects, people, or animals is required: supply chain (Wamba *et al*, 2006), consumer goods tracking (Resatsch *et al*, 2007), anti counterfeiting (Tuyls & Batina, 2006), access control (Thornton, 2006), healthcare (Ho *et al*, 2005), libraries (Walczyk, 2009), ubiquitous applications (Segatto *et al*, 2008), payment systems (Thornton, 2006; Wall Street Journal, 2011), entertainment (Rashid *et al*, 2006), luggage tracking (DeVries, 2008) and others. 2D barcode technology also has its established areas of applications: universal product code (EPC), logistics, manufacturing, ticketing, healthcare, transportation, mobile phone applications, rental services and other applications (Rukzio *et al*, 2006; Mäkelä *et al*, 2007).

1.4 Pervasive mobile learning environments

Pervasive mobile learning is a subset of m-learning where the roles of intelligent environment and context are emphasised. The physical environment has a central role as it provides context for learning, content for learning, as well as system resources (Laine and Joy, 2008). Compared to other learning environments such as classrooms or field trips, pervasive m-learning environments provide personal, engaging and attractive interaction between the learners, the environment and the relevant educational content. Furthermore, in properly designed pervasive m-learning environment, content is delivered in a correct format at the right place in right time. Pervasive m-learning environment can be deployed not only in traditional learning contexts but also for example in corporate training settings, museums, exhibitions and tourist attractions. Some examples of pervasive m-learning environments include SciMyst (Islas-Sedano *et al*, 2007) and LieksaMyst (Laine *et al*, 2009). Furthermore, pervasive m-learning applications have also been used for language learning (Beaudin *et al*, 2007; Ogata *et al*, 2006).

Pervasive m-learning environments have been utilising both 2D barcodes (e.g. Islas-Sedano *et al*, 2007) and RFID (Ogata *et al*, 2006). However, thus far we have no evidence on studies which compare suitability of these smart tagging technologies for pervasive m-learning environments.

1.5 RFID and 2D barcode in previous work

A search of studies that cover mobile RFID and 2D barcodes interaction technologies gives few results. For example, Rashid *et al* (2006) introduces Bluetooth and RFID technologies for location-based games using mobile phones, like the “Pac-Lan”, a game inspired by original “Pacman” game. Another example of a pervasive mobile game is “Mobio Threat” that combines different wireless technologies (Segatto *et al*, 2008) - RFID, IrDA and QR code are used for object interactions, and communication between players and the server is established by Bluetooth and Wi-Fi. Several articles described physical gestures like touching an RFID tag or scanning a visual tag in different contexts (Salminen *et al*, 2006; Välkkynen & Tuomisto, 2005).

One paper (Mäkelä *et al*, 2007) is dedicated to a field study of user mobile interaction with visual (QR code) and RFID tags. 50 random people from Finland were participating to the research where goal was to assess the knowledge and expectations of people regarding smart tagging technologies. Study was conducted by suggesting a person to interact with given a poster having an embedded tag and a device set up to interact with that tag. Person was not informed on how to interact with it. Each test set included RFID tags and QR codes embedded to posters and devices for reading them. The study uncovered usability problems, misconceptions, and lack of experience and knowledge about RFID and visual tags for the majority of participants. Tags' function was regarded by the participants as data storage in an encrypted form rather than as an Internet link. As a result of study, RFID was considered to be more interactive and to have wider functionality. Scanning QR code by taking a picture was considered to be more familiar, but less intuitive in understanding of interaction principle.

1.6 Contribution

Our work has two main technical contributions: (1) development of a NFC/RFID plugin for MUPE; and (2) development of a pervasive memory game for training memory and learning vocabulary. These developments were prerequisites for the comparison of the two smart tagging technologies, namely 2D barcode and RFID, in an educational setting. Our development efforts are described in the following sections.

2. DEVELOPMENT AND EVALUATION

2.1 MUPE and plugin development

Multi-User Publishing Environment (MUPE) is a developing platform for mobile multi-user context-aware applications. It comprises a Java/XML-based server and a J2ME-based client for mobile devices. Main advantage of MUPE is that only server programming is required to build applications as all content is pushed to a client in XML format. The client then renders the content to an equivalent J2ME-based user interface. One client can subscribe to several services (servers) and one server can host multiple clients. Communication between MUPE server and client is depicted in Figure 2.

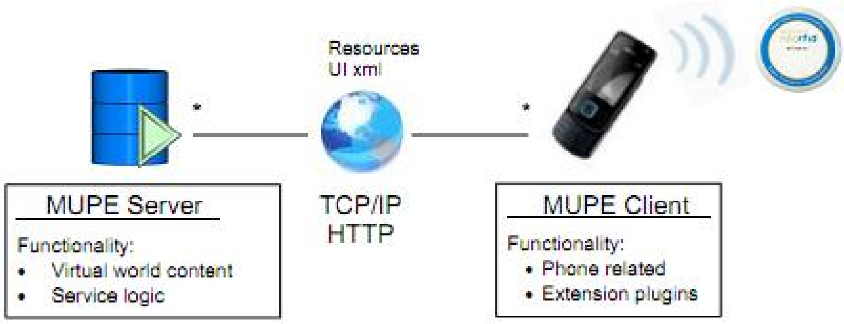

Figure 2. MUPE architecture

MUPE development allows fast prototyping and makes maintenance of applications very comfortable due to dynamic content architecture. MUPE has been used before for developing pervasive mobile learning environments such as SciMyst (Islas-Sedano *et al*, 2007; SciMyst, 2011) and LieksaMyst (Laine *et al*, 2009).

MUPE client supports third party plugins (e.g. GPS and Bluetooth) for extending its basic functionality. MUPE's plugin interface allows a developer to create new plugins quickly. 2D barcode (Semacode) reader plugin was previously developed. However, for the sake of comparing the two smart tagging technologies, we had to develop a NFC/RFID plugin for MUPE, thus we wrote a plugin that connected MUPE client to mobile device's NFC reader hardware. The NFC/RFID plugin allows reading contactless tags with MUPE application through a RFID enabled mobile phone. At this stage our plugin supports only reading of NDEF (NFC Data Exchange Format) tag types but the range of supported tags can be easily extended.

2.2 MemGame

In order to compare the 2D barcode and RFID technologies with users, a game application was developed. The application is a pervasive memory game that utilizes RFID and 2D barcode technologies. The game has two educational goals: memory training and language learning. It has two modes: *NFC* and *Semacode*. The NFC mode utilizes RFID technology and uses the developed NFC Plugin. Semacode game mode uses the Semacode plugin and is based on reading 2D Barcodes. Figures 3a and 3b show the main menu and the game board of the game user interface.

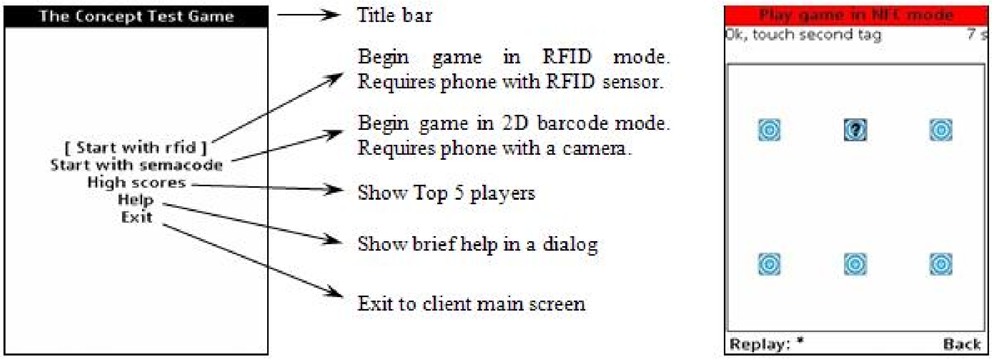

Figure 3a and 3b. User interface of MemGame

NFC and Semacode (with 2D Barcode) modes share the same basic idea. Let us consider the operation of the game through a usage scenario where a player has selected *Start with RFID* (NFC mode) in the main menu. An even number RFID tags are placed on a table to form a rectangular game board. RFID tags on the table are mapped to the cards on the screen (see Figure 3b). The size and composition of the game board is determined by the researcher before the actual game starts. Each tag has its own unique ID. Word pairs are assigned to tags in such manner that two tags share identical pair. When the game starts, the player "touches" a tag, the phone vibrates as the NFC plugin successfully reads the tag and the word is shown in a dialog according to the data stored the tag. As the player touches consecutively two tags with the same associated text, the phone notifies him/her with a dialog box and a sound, and those two tags are removed from the card map on the mobile screen. Game continues until the player uncovers all the tags and it may be restarted at any time. Restarting the game shuffles the virtual game cards to form new pairs randomly.

2.3 Study setting

The usability study took place in December 2008 at the University of Joensuu (University of Eastern Finland). The testing included playing the MemGame game with RFID and 2D barcodes and filling a questionnaire. The testing environment included the following components:

1. Testing devices were Nokia 6212 classic NFC, Nokia 6212 NFC and Nokia N95. First two devices are NFC enabled and were used for playing the game in the NFC mode, while the latter was used in the Semacode mode for playing with 2D barcodes. As MemGame is a multi-user application, several users may play it at the same time. In the test a maximum of two users were playing simultaneously.
2. Each device had a MUPE client (with Semacode and NFC plugins) preinstalled and launched. The game board was prepared ready for playing.
3. Test was conducted in a laboratory room with good illumination and minimized distractions.
4. MemGame service was running on a dedicated server to which the clients connected via 3G connection.
5. RFID/NFC tags – a set of six Trikker-1k CL42 RFID sticker labels based on Mifare standard 1k chips. Each tag had an NDEF record with a number as payload.
6. 2D barcodes – a set of six Semacode 2D barcodes were prepared. Each 2D barcode had an integer number of three digits encoded in it.

The test consisted of three consecutive steps. The first step was filling in the "before test" section of the questionnaire. Users were asked to put their personal information and answer several questions regarding their preliminary experience and expectations regarding 2D barcode and RFID technologies.

The second step of the test was to play the game in two modes. Before playing, users were instructed on how to interact with RFID tags and 2D barcodes as well as how to play a mobile memory game. Then each participant started to play from the initial game screen and played it until the end. About half of participants started playing the NFC mode first and another half the Semacode mode first. Figure 4a shows an example of interaction with 2D barcode. User points a camera of a mobile phone (Nokia N95) to a visual tag and presses a button to take a photo in order to decode the tag. In the NFC mode (Figure 4b) the process of interaction is simplified because decoding the tag requires only approaching an NFC enabled phone close enough to a tag.

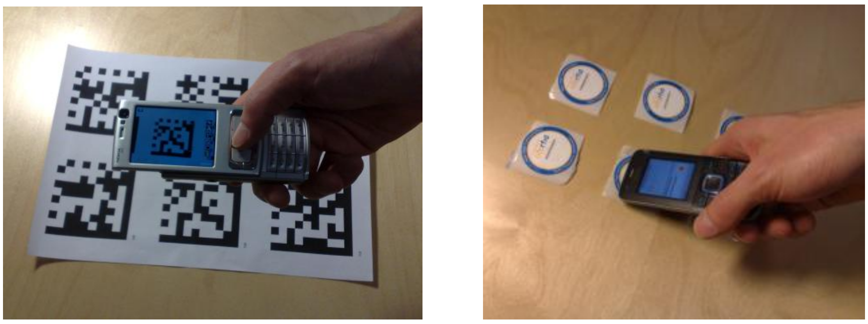

Figure 4a and 4b. Interaction with tags in Semacode and NFC modes

As the final step of the test, the players filled the latter part of the questionnaire which measured the experiences after gaming as well as preferences of using each of the technologies in various settings.

2.4 Study results

There were seventeen volunteers (five female, twelve male) from 22 to 30 years who were invited to participate in this usability study. Only few participants were familiar with RFID technology while most of them (12) used or saw 2D barcodes previously in their lives. None of participants had a strong experience or used 2D barcodes technology in everyday life. At the same time, among the participants who did not see those technologies, most of them (7) heard about RFID technology.

Figure 5a shows user expectations regarding usage of RFID and 2D barcodes. Convenience and speed of interaction were deemed to be important features of smart tagging technologies. These features have a direct influence on the process of interaction and on what the participants would prefer for further use. As RFID and 2D barcode technologies both allow successfully performing related tasks, it is possible to rank them by applying such criteria. Convenience affects user's satisfaction while the speed of retrieving data from a tag measures effectiveness and efficiency of the respective technology. From Figure 5a we can clearly see that most of the participants (75%) considered RFID technology to have the best performance and convenience attributes in comparison to 2D barcodes already before the test.

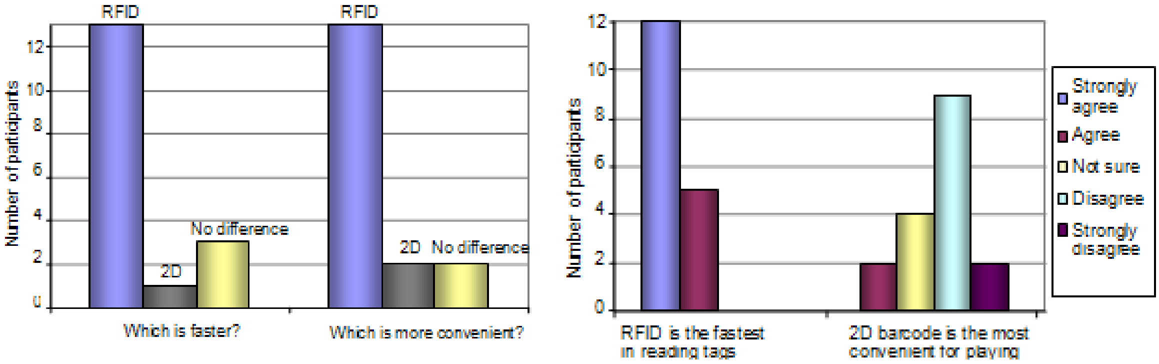

Figure 5a and 5b. Convenience and speed

After the test, all participants agreed (12 strongly agree and 5 agree) that RFID had shown the best performance on reading the tags (Figure 5b). This means that four persons that previously thought either that there is no difference or 2D barcode is faster (Figure 6a, "Which is faster?") changed their minds towards superiority of RFID. Only two participants preferred 2D barcodes as more convenient than RFID, while eleven participants (9 disagree and 2 strongly disagree) thought otherwise. Four persons doubted in their preferences. These results show that RFID technology was considered to be the fastest in reading tags and only two of seventeen participants considered 2D barcodes to be more convenient.

Participants provided their feedback on what technology they would prefer to use in suggested scenarios. These preferences are shown in Figure 6. In all scenarios RFID was the most preferred but the number of participants preferring 2D barcodes approaches to the number of participants preferring RFID in some of the scenarios. For example, seven people against ten preferred using 2D barcodes to access a website of a movie through a poster and marking own belongings for the case if they get lost and the finder could contact them. At the same time, fifteen participants against two preferred shopping in a favorite supermarket and playing context-aware mobile games with RFID technology.

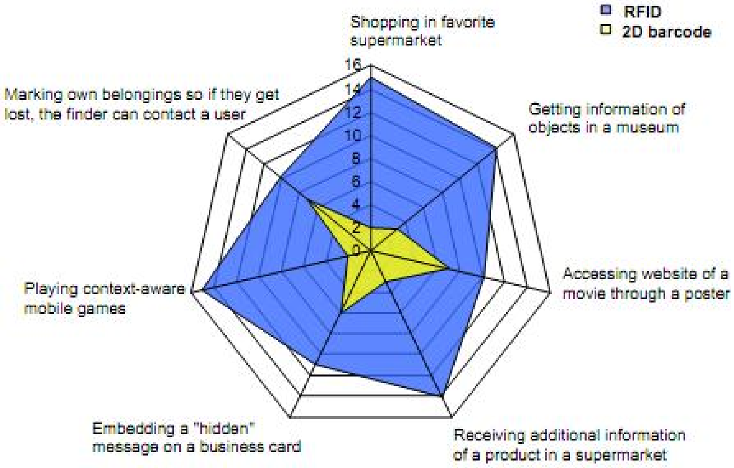

Figure 6. User preferences for using smart tagging in everyday life

Players' performance data shows that NFC mode outperforms Semacode mode in time performance of users as the average time of completing the NFC mode is twice less than in the Semacode mode (Table 2). The main reason for this is the additional time needed to take photos. In the case of RFID, the data is encoded into an electronic chip and can be retrieved directly and quicker compared to 2D barcode. Thus, using RFID might be a better solution in pervasive applications where interaction speed is an important or critical factor.

Table 2. Users' performance in MemGame

	NFC			**Semacode**		
	Time (s.)	**Score (pts.)**	**Mistakes**	**Time (s.)**	**Score (pts.)**	**Mistakes**
Min	**40**	1323	**0**	68	1387	2
Max	**178**	6059	12	316	5653	**6**
Average	**69**	3446	4	143	3386	**3**

Performance results also show that the minimum number of mistakes (incorrect card pairs) players did is lower for the NFC mode. At the same time, the minimum average amount of mistakes belongs to the Semacode mode. The reason for this might be that the players have more time thinking and remembering the data encoded to 2D barcodes as the time performance shows. Possibly this allows avoiding mistakes.

3. CONCLUSION

Smart tagging technologies are used to enable context-awareness in pervasive mobile learning environments. In this paper, we first reviewed a body of literature regarding smart tagging technologies as to compare the technologies from theoretical perspective. We then presented a usability comparison of RFID and 2D barcode smart tagging technologies in an educational setting, namely in a pervasive mobile learning environment for memory and language training. In order to perform the comparison, we constructed an NFC plugin for MUPE and developed the pervasive MemGame. 2D barcode plugin was developed previously.

Results of the comparison test suggest that RFID was generally considered both faster and more convenient to be used before and after the playing the game. However, players did fewer mistakes with 2D barcodes than with RFID. Questioned about the preference of each smart tagging technology in everyday life scenarios, the users mostly preferred RFID. Based on these findings we can conclude that the learners may be ready for RFID as a potential technology for pervasive learning environments and everyday life scenarios. On the other hand, in some cases 2D barcode may still be superior, especially due to the lack of suitable reader devices and the price difference of RFID and 2D barcode tags. We therefore recommend that developers of pervasive learning environments should carefully consider whether the speed and convenience of RFID tags are enough to sacrifice cheap 2D barcode tags and a wide array of supported mobile devices.

In the future we will utilise the NFC plugin in other pervasive learning environments where speed and convenience of tag reading are critical features. It remains to be seen whether RFID can take barcode's position as the de-facto tagging technology of objects.

REFERENCES

Beaudin, J.S. et al, 2007. Context-Sensitive Microlearning of Foreign Language: Vocabulary on a Mobile Device. *Proceedings of the European Conference on Ambient Intelligence.*

DeVries, P., 2008. The state of RFID for effective baggage tracking in the airline industry. *International Journal of Mobile Communications*, Vol. 6 No. 2, pp. 151-164.

Glover, B., and Bhatt, H., 2006. *RFID essentials.* O'Reilly, Sebastopol (CA).

Ho, L. et al, 2005. A prototype on RFID and sensor networks for elder healthcare: progress report. *E-WIND '05.* ACM, New York, NY, pp. 70-75.

Islas-Sedano, C. et al, 2007. Where is the answer? – The importance of curiosity in pervasive mobile games. *FuturePlay 2007 Conference.*

Laine, T.H. and Joy, M., 2008. Survey on Context-Aware Pervasive Learning Environments. *Proceedings of the MLearn 2008 Conference.*

Laine, T.H. et al, 2009. Uncovering the richness of an authentic living museum through pervasive learning environment. *Accepted to the International Conference on Advanced Learning Technologies*.

Mäkelä, K. et al, 2007. Mobile interaction with visual and RFID tags: a field study on user perceptions. *CHI '07, ACM*, New York, NY, pp. 991-994.

NFC forum official site. Retrieved April 10, 2011 from http://www.nfc-forum.org/aboutnfc

Nokia. "Scan and decode mobile codes". Retrieved April 10, 2011 from http://mobilecodes.nokia.com/scan.htm

Ogata, H. et al, 2006. Supporting Japanese Mimicry and Onomatopoeia Learning with Sensors. *Proceedings of the Fourth IEEE International Workshop on Wireless, Mobile and Ubiquitous Technologies in Education.*

Rashid, O. et al, 2006. Extending Cyberspace: Location Based Games Using Cellular Phones. *ACM Computers in Entertainment,* Vol. 4, No. 1. Article 3C.

Resatsch, F. et al, 2007. Mobile sales assistant: NFC for retailers. *MobileHCI '07.* New York, NY, Vol. 309, pp. 313-316.

Rukzio, E. et al, 2006. An Experimental Comparison of Physical Mobile Interaction Techniques: Touching, Pointing and Scanning. *Proceedings of Ubicomp.* Pp. 87-104.

Salminen, T. et al, 2006. Enhancing Bluetooth Connectivity with RFID. *Proceedings of the Fourth Annual IEEE International Conference on Pervasive Computing and Communications (PERCOM'06).* pp. 36-41.

SciMyst. Retrieved April, 2011 from http://www.cs.joensuu.fi/SciMyst/2007/Whatisit.htm

Segatto, W. et al, 2008. Mobio threat: A mobile game based on the integration of wireless technologies. *Computer Entertainment*, Vol. 6, No. 3, pp. 1-14.

Thornton, F., 2006. *RFID security*. Syngress Publishing, Rockland, MA.

Tuyls, P., and Batina, L., 2006. *RFID-Tags for Anti-counterfeiting.* D. Pointcheval: CT-RSA, LNCS 3860, pp. 115–131.

Välkkynen, P., and Tuomisto, T., 2005. Physical Browsing Research. *In Pervasive 2005 Workshop on Pervasive Mobile Interaction Devices.*

Walczyk, D., 2009. RFID and Its Message. *Library Journal*, Vol. 134 No. 1, S4-S7.

Wall Street Journal. "Google Sets Role in Mobile Payment". Retrieved April 10, 2011 from http://online.wsj.com/article/SB10001424052748703576204576226722412152678.html

Wamba, S. F. et al, 2006. Enabling intelligent B-to-B eCommerce supply chain management using RFID and the EPC network: a case study in the retail industry. *ACM International Conference Proceeding Series.* New York, NY, Vol. 156, pp. 281-288.

Wikipedia Foundation. "RFID". Retrieved April 10, 2011 from http://en.wikipedia.org/wiki/RFID