Potentials and Challenges of Mobile Media in Museums

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Abstract

In the context of life-long learning implementation of mobile media in museums is increasing. However, current applications do not tap the full potential offered by the special characteristics of this technology. Based on a literature review different potentials giving benefits to the visitor experience and the museum are presented and innovative applications

discussed. Implementation, technology, and evaluation of mobile media applications in museums pose a challenge for museums as well as current research and development.

1 Introduction

With the increasing relevance of life-long learning, informal settings like museums gain in importance. This article addresses learning with mobile handheld devices in museums as an important example of life-long learning in informal settings [Some differences remain, e.g. museum visitors have only a short time to get accustomed to the use of the device. As the device is owned by the museum and will not be personalised as much as a private PDA; created or retrieved content must be transferred to another device to be accessible after the visit.]. Informal learning settings in contrast to formal ones are generally characterized by high autonomy of the learner, no formal evaluation, and fleeting situational interest. In this review article we discuss the potentials and challenges of mobile media in these informal settings and museums in particular from a psychological viewpoint. We are going to focus on personal digital assistants (PDAs). Although cell phones vastly outnumber Personal Digital Assistants (PDAs, small, handheld computers), we expect that PDA functionality will become standard in future generations of cell phones (like today's "smart phones"). As a consequence we focus on the functions and potentials of today's PDAs since they will probably become as widely used and familiar as cell phones are today.

1.1 Mobile Devices in Museums

It is important to realize that there is no "typical visitor" of a "typical exhibition" in a "typical museum": Visitors across and within different exhibitions are usually very heterogeneous (e.g., regarding age, gender, prior knowledge, interests, goals) and vary between different types of museums. Exhibits can be displayed in many different ways: From a "classic",

neutral style in front of a “white wall” or in a display case without any or minimal information (especially in art museums) to a highly interactive, media dominated style (especially in science centers). Museums addressed here are such of art, science and technology, history, local history, ethnography folk, modern art, fine arts and many more. They can be in a building, open-air or mixed. For the purpose of this article, they may also include botanic gardens, aquariums, zoos and science centres.

Mobile technology in museums is often used for provision of information and as guides. While the classic audio-guide is common, more and more museums begin to use PDA-like devices. They can still display audio information, but also visual information (static and animated) and can be flexibly configured (e.g., regarding user interface or functionality). Although they generate a lot of attention, their value – for visitors and museums alike – is doubtful. In this article we want to point out and discuss the specific strengths and challenges related to different characteristics of mobile devices in museums from a visitor and a museum point of view.

1.2 Characteristics of Mobile Technology

There are special characteristics of mobile technologies, which can add to the visiting experience in a museum and which will be addressed in this paper:

Made to be mobile

PDAs must be small and lightweight to be easily carried around. This requirement leads to small screen sizes and reduced input keys. Displaying much information at one time or entering large or complex amounts of data are challenging to impossible, especially for visually impaired persons or children with reduced motor control.

The mobility itself offers unique advantages compared with fixed terminals or even notebooks: The information and applications on the PDA can easily be accessed any time (even on the move) and anywhere in the museum (i.e., in the natural context).

Made for connectivity

PDAs offer a number of interfaces for data exchange (e.g., WLAN, Bluetooth, infrared, RFID). Real time updates of content (e.g., exhibit information, guided tours, special events) are possible, providing a greater flexibility with information. Content can also include the visitor's spatial position (location-awareness), providing the current position on a map and leading the visitor to interesting exhibits or giving location specific information. Communication with other visitors (in different parts of the museum) is feasible, allowing groups to experience the museum separately but remain in constant contact.

Made for a personal experience

As the name states, the device is a personal digital assistant, made for a single user. Instead of an (often) shared computer terminal or large screen projection (Hornecker, & Stifter, 2006), the PDA's small screen size and frequent use of audio makes sharing a single device difficult or impractical. However, it allows using adaptive programming and personalised content to provide an individualised visit, tailored to the interests and capabilities of the visitor (e.g., age, prior knowledge and time constraints; cp. Naismith, Lonsdale, Vavoula, & Sharples, 2004, p. 33). If this user-awareness is combined with the above mentioned location-awareness, powerful, fully context-sensitive applications are possible, providing the "right information, at the right time, in the right way" (Ogata, & Yano, 2003, p. 1). On the other hand, since visiting a museum is a social event (Gammon, 2004) visitor-medium interaction may reduce visitor-visitor-interaction (Proctor, 2005) and inhibit knowledge and information exchange with other group members (cp. Treinen, 1988).

It is important to use this inherent features and functionalities of mobile media in an effective way and thereby, offer the visitor a personalized experience (Gay, Spinazze, & Stefanone, 2002). We are going to discuss the potentials, but also challenges of these PDA characteristics.

2 Potentials for Mobile Applications

Daniel Molitor (Exploratorium, 2001, p. IV-1) invites developers of mobile technologies to ask the question "why are we doing this? Is it just because the stuff is out there and we're hip and cutting edge, or is this adding something fundamentally?" Mobile applications have the potential to add something fundamentally, if implemented in a purposeful way. We want to explore in this paper some of these potentials for the visitor experience and for the museum (cp. table 1).

Table 1: Potentials for mobile applications

Visitors' Perspective	**Museum Perspective**
Provision of information	CMS for exhibit information
Allowing a personal emotional experience	Tracking visitor behaviour
Interactive programs	
Computer mediated interaction	
Expanding experiences beyond the museum visit	

2.1 Visitors' Perspective

2.1.1 Provision of Information

Personalized Information

The simplest way of use for mobile technologies in museums is to act as "digital, mobile labels" for exhibits (text or audio). But a PDA can go further and provide highly personalized information, adapted to visitors' characteristics (e.g., age, impairments, media preference, prior knowledge), interests (explicit adaptivity, e.g., Kruppa, Lum, Niu, & Weinel, 2005) or prior movements (implicit adaptivity, e.g., Not, Petrelli, Stock, Strapparava, & Zancanaro,

1997). If information matches visitors' prior knowledge and interests, they gain most benefit from this kind of information, as knowledge has to be constructed individually and personalised information can be integrated more easily into existing knowledge structures (Scanlon, Jones, & Waycott, 2005, Tobias, 1994).

Access to Diverse, Interest Fulfilling Information

Authentic exhibits may stimulate curiosity and situational interest, a fleeting, situational dependent desire for more and deeper information (Loewenstein, 1994; Valdecasas et al., 2006). PDAs provide the museum with the ability to fulfil visitors' situational interests on the spot (Proctor, 2005). They can go beyond size restricted text labels and make broader and deeper information available, choosing from a wide knowledge base the information most appropriate for the individual visitor (e.g., online access to Wikipedia to answer arisen questions). If interest is satisfied in this way it might lead to better learning performance through more elaborate learning strategies (Wild, Krapp, & Winteler, 1992). Repeated exposure to situational interest can lead to dispositional (stable) interest, independent of the situation the visitor is in. The interest may even become epistemic: It expands and grows leading to greater knowledge and skills. This is of high relevance in a museum, since this setting provides little formal or extrinsic motivational factors.

Location Specific Information

In addition to exhibit information, a PDA can make spatial information available to visitors, for example suggesting tours (Bright et al., 2005; Teo, 2005), displaying the current location on a map and the best way to see preferred exhibits, and shows or even finds the nearest toilet. Based on personal information the system may also recommend exhibits in the vicinity.

Unobtrusive Transmission of Information

Besides content-information, the way in which information reaches its addressee is also improved. PDAs equipped with headphones provide information only to the addressee, without disturbing other visitors' "silent dialogue" with the exhibit. While this is an issue in

some art museums (with a norm to be quiet), it is also important for media centric installations, when loud audio coming from different installations compete for visitors' attention, creating a high background noise. It can also be used if a large media screen is combined with auratic objects, as in the "Mercedes-Benz Museum" in Stuttgart, Germany. It uses the headphones of their audio guides for all audio information, even from installed, large screen videos. This allows the viewer to follow the video without distracting other visitors who are engaged in the exhibits.

2.1.2 Allowing a Personal Emotional Experience with the Exhibit

An important issue in displaying an exhibit is the tension between "letting the exhibit speak for itself" and providing information to allow visitors to establish a meaningful relationship to the object. It is feared that too much (or any) information would distract form the exhibit. This might destroy the "aura" of an exhibit, a feeling of awe created by unique or remarkable objects (Benjamin, 1936). This emotional feeling of being impressed, amazed, or even touched may be a principal reason why people visit exhibits. Valdecasas, Correia, and Correas (2006) argue, that the "wonder of the exhibit" has been lost – partly through media installations. It is assumed that a PDA provides an unobtrusive way to provide necessary information to personally situate an exhibit without destroying the visitors' feeling of wonder. However, Walter (1996) found that introducing mobile guides to an ancient Roman bath resulted in less interaction with exhibits. This might be due to problems with design of the mobile guide. While mobile devices did claim visitors' attention, unfortunately it was not evaluated if the emotional component was also affected. The challenge of integrating media without distracting from the object itself (i.e., "without disturbing the aura of an exhibit") is addressed later in this paper.

2.1.3 Interactive Programs

PDAs can also create an interactive engagement with the exhibit, letting the visitor become a part of it. An example of such an application would be the Tate Modern, where users could select music which they regarded as most appropriate for the artwork looked at (Proctor, & Tellis, 2003). Such individual design activities can also be expanded socially by boundary objects available to other visitors (Fischer, Giaccardi, Eden, Sugimoto, & Ye, 2005).

2.1.4 Computer Mediated Interaction

Interaction within visitor groups can be supported by PDAs in different ways. As it was observed that visitor-visitor-interaction decreases when visitor-PDA-interaction increases (cp. challenges, Walter, 1996), this potential is very important to come up to (Gay et al., 2002). A shared experience provides common ground for communication and discussion, which in turn is able to enhance elaboration of information and the visiting experience as a whole (Clark, & Brennan, 1991; Thompson, & Fine, 1999). Some museums integrate a communication function within their mobile guides to enable electronic communication within or across visitor groups (e.g., Teo, 2005).

Especially for school classes and children a playful approach to a museum visit can be supported by use of PDAs (e.g., treasure hunts, cp. Molitor, 2001). Play is seen as a powerful mediator for lifelong learning and interest development (Rieber, 1996).

Mobile devices can expand social interaction also beyond existing visitor groups. Two possibilities of social navigation are suggested by Höök (2003): Collaborative annotations (cp. also Stevens, & Toro-Martell, 2003) embed an existing object socially. Another way could be social awareness systems like at amazon.com ("Other persons who visited this exhibit also visited ..."). Also social recommendations for objects ("Have a look at ...") or votings/pollings could embed a visit socially (Proctor, 2005), as opinions of others often influence information processing in an important way (cp. Levine, Resnick, & Higgins, 1993).

One step further would be access to a museum specific Wiki, allowing visitors to share knowledge about the displayed exhibits. This would tap the available expertise of visitors who may have an extensive background knowledge or personal experience with the issue at hand (e.g., a retired photographer who has actually used an old camera and knows interesting details/stories about it or a collector who might spot inaccurate information). Since the text structure and formatting is also changeable, the knowledge gap between experts (curators) and novices (inexperienced visitors) may be bridged by more knowledgeable visitors who can share both perspectives. This would also take visitors more seriously, allowing knowledge exchange with the museum at eye level.

2.1.5 Expanding Experiences beyond the Museum Visit

While a museum visit may be an interesting event in itself, it should not be an isolated or unprepared event. Mobile technology can support visitors' preparation and follow-up of visits.

Preparation to Visit

While visitors may plan in advance which museum they want to visit, they usually do not review information about the topics, exhibits, or layout of the exhibit in advance. As a consequence, visitors first need to orientate themselves, get an overview of the exhibits, find the selected few exhibits that are interesting for themselves and are anxious to miss anything important. However, a museum can offer a quick overview of its exhibits on its website (which the potential visitor might view to get more information about the location and opening times of the museum) and allow to "bookmark" interesting exhibits to design a personal tour. Via a password visitors can access this information on their mobile device in the museum and be guided by the device to these objects. This is currently implemented in the Ueberseemuseum in Bremen, Germany. Also such preparation will result in a more focused visiting strategy and can enhance learning (Falk, Moussouri, & Coulson, 1998).

Visit Follow-up

Given the short amount of time visitors spend in exhibitions, PDAs can be used to bridge the gap between the time in the museum and the time after the visit (cp. "Rememberer" by Fleck et al., 2002; RFID-solution in Hsi & Fait, 2005; "learning trails" by Walker, 2006). Bookmarks of interesting exhibits saved on a personal webpage created for each user can serve as remembrance and as connection point for further exploration. This webpage may link a visitor's personal interest for specific exhibits in the museum to post-visit learning activity or serve as base for later social interaction. Such a webpage uses the information about visitors' interests, already expressed by viewing specific exhibits, and prevents giving unspecified information (like a complete catalogue of the exhibition) where visitors would have to find the objects of their interests again. Besides explicit bookmarks, this "interest trail" can further be enhanced by implicit information, for example the times spent at specific exhibits or research activity in available databases (as indicator of situational interest).

2.2 Museum Perspective

Implementation of mobile devices in museums offers multiple benefits not only for the visitor, but also for the museum itself. However, they require a lot of effort, restructuring and are no money makers. We will address the benefits here and return to the challenges later.

2.2.1 CMS for Exhibit Information

If exhibit information (e.g., labels with descriptions and background) is fully digitalised, it can be revised centrally, directly from the curator's office. Depending on the available connection to the database, information on the guides is updated immediately (if access via WLAN is used) or after the next synchronisation. In this way exhibit information should be always up-to-date. As mentioned earlier, museums could also benefit if mobile devices are used for computer mediated interaction between museum staff and visitors. Visitors' feedback, knowledge, but also questions and comments would be available to the curator, allowing him to get closer information about the exhibit and visitors' reaction to it.

Another benefit would be convergence of texts in a CMS: Information in the database can be used for information presentation on PDAs, media terminals in the museum, and texts on the website. Thereby the same content serves different purposes.

2.2.2 Tracking Visitor Behaviour

Mobile devices provide the museum with rich information about visitor behaviour. Information about visitors can be accessed in real time, for example watching visitor flow, aggregations of visitors or getting an overview about the amount of visitors in the museum at all times. Locating a lost child or the last visitors before closing time would be relatively easy. As information about visitor behaviour is available digitally, statistical analysis of visitor behaviour can be done easily and fast:

1. Which exhibits gain most attention?

By automatically collecting personal (e.g., age, interests, prior knowledge) and temporal-spatial (way through the exhibition, time spend at specific exhibits) information a detailed picture of visitor behaviour can be created. "Hotspots" of high visitor interest (total or for specific visitor groups) can be easily identified and future exhibitions can be tailored to address these interests. This might heighten visitor satisfaction and increase the number of visitors. Important objects, which are ignored by visitors, can be presented in different ways to find out how they can gain more attention. The feasibility of this approach was tested with smartcards (giving only location information) by Hornecker and Stifter (e.g., 2006).

2. Which information do visitors retrieve from the PDA?

Mobile applications can be designed to match visitors' needs more properly, if museum designers know what kind of information they require and when. Log files and questionnaires indicate problems with interface and content, to continually improve the system.

3. How many visitors come? How long do they stay? Do they like the exhibition?

Basic information about visitors is automatically collected and can be accessed easily. Visiting time can be used as an indicator for satisfaction and interest. Supplemented by short multiple choice questionnaires, this visitor information can be automatically processed and related to other visitor characteristics like age, prior knowledge, etc. This way every visitor is a participant in a visitor study, providing the basis for long-time statistics of previously unprecedented levels of detail, continuity and accuracy.

3 Challenges of Mobile Applications

Some of the potentials discussed above have already been implemented by some museums; others are still waiting to be realized. To put these ideas into practice, different challenges have to be overcome. In this section we want to give a short overview on some challenges for visitors and museums before we discuss specific challenges of creating mobile applications for museums (regarding content, device/interface design, and technical issues).

3.1 Challenges for Visitors

3.1.1 Computer Literacy

Although museums often provide a short introduction (often delegated to a large sign) and the interface is designed as simple as possible, some visitors will need help in using the device. As Gammon (1999a, 1999b) described to the point, visitors often do “get it wrong”. Demands on visitors that are too high will lead to increased strain on the staff or visitors’ rejection of the devices.

3.1.2 Engaging with Mobile Technology

An increased reliance on mobile devices poses challenges for visitors. Some visitors explicitly and consequently reject technology in museums, especially in museums of art. While this may be in part due to a lack of computer literacy, it can also be a matter of principle. For these

visitors, who regard a museum as (digital) media-free zone, a museum that relies completely on mobile devices (no labels at all but information only available on context-sensitive PDAs) would not be accessible.

3.2 Challenges for Museums

Even if mobile technology is only used in addition to existing information, it poses structural and financial challenges.

3.2.1 Structural Challenges

While using the existing cash box as place where the devices are lent to the visitors, the additional task poses a stress factor for the personnel. Explaining visitors the use of the PDA – which some will require or need even if the device seems self-explanatory – will lead to increased waiting times for other visitors. Visitors will return if they have technical difficulties or a lack of computer literacy, requiring further help (and time) by the personnel. An introduction on the use of a PDA and support for visitors is important if mobile guides are introduced (Wise, & Lawrence, 2001). If the system is too complex or unstable and the personnel not sufficiently trained, this will lead to dissatisfaction and rejection of the device by the visitors. Also personnel might become reactant to give out the devices and for example "forget" to mention that the devices are available or signal in subtle ways that they are a waste of time. An often necessary solution is a second stand after the checkpoint to give out the devices and whose personnel assist visitors in using them. A related problem is the necessity to make sure that the devices and all its components (including memory cards) are returned by the visitor after the visit, which requires a sophisticated security system, close observation, and/or alarms at the doors.

3.2.2 Financial Challenges (acquisition, staff, maintenance)

Costs for mobile devices should not be underestimated. While the devices get more powerful and cheaper, broken or missing devices still need to be replaced. Maintenance is also necessary, as is new and trained personnel (cp. structural challenges; Proctor, 2005). However, given the trend towards more and more functionality on cellular phones, exemplary in the recent introduction of the Apple iPhone [The iPhone was introduced at Macworld San Francisco 2007 on January 9, 2007 while this article was in review.], using the technology of visitors might overcome most of these problems. Museums could provide the infrastructure (WLAN) and focus on their core competency: the content itself. They could provide visitors with context-sensitive (personalised, location specific) information on their phones' browser and let them save information on their devices. A (smaller amount) of PDAs for visitors without smartphones or are not willing to use their own devices might be provided by the museum.

3.3 Challenges of Creating Mobile Applications for Museums

In this chapter we want to address some challenges for content development, design and technical implementation of mobile devices in museums (cp. table 2). A good overview of issues to consider when implementing mobile media for tourism in general is found in Hornecker and Bartie (2006).

Table 2: Challenges of creating mobile applications for museums

Content	Device/Interface Design	Technical Implementation
"What?"	"How?" "Which way?"	"With what?"
Available information Copyright if information is made available beyond	Usability Visitor attention Device design	Location-aware technology Stable and fool proof system Rugged hardware

museum boundaries		

3.3.1 Content ("What?")

While the device itself can carry a lot of information, creating the right content is a difficult task for museums as well as for program developers.

Available information

In most cases, information has to be produced especially for presentation on PDAs. Existing texts (e.g., from labels, internet, or scientific databases) are often unsuitable in length and content. Visitors are a heterogeneous group with different interests and prior knowledge. The device must address their individual requirements. If material is presented adaptively to visitors' needs (visitor characteristics, interests, prior knowledge, or prior movements) the visiting experience should be more satisfactory for a visitor. But this approach requires also more material, as different sets of information must be produced. Visitor feedback like it is known from technical help sites on the internet ("Was this information helpful for you?") paired with personal information of the visitor (e.g., age, interests, prior knowledge) can be used to continually improve material.

Another approach to material production would be the use of a museum Wiki to get visitors' perspective and texts from visitors for visitors (see 2.1.4). Social tagging might also be used (for a web-based solution see: Fine Arts of Museum San Francisco [http://www.thinker.org]). An open question is, whether visitors will be willing and competent to provide this information. Also the question of qualitative control poses a challenge to museums: They can either control it themselves (with high personnel requirements), drop the claim of presenting correct expert knowledge, or clearly signal the boundaries between professional and amateur knowledge.

Access to internet sources (e.g., Wikipedia or Google) might also be an alternative to creating new information. The access can be data-mined, although it might needs to be restricted or raises legal concerns if visitors misuse the internet access to download illegal material or minors use it to access mature content.

Copyright if information is made available beyond museum boundaries

If visitors are allowed to transfer digital media to their home computers, the release of material might pose a challenge for museums, as it is often copyrighted. Even if the museum has the copyright of the works, relenting them for the visitors might be rejected since it could be seen as losing a source of income (postcards/catalogues in museum shops) or strength of the museum (material is only available inside). On the other hand, relinquishing copyright might be seen as advantage to some museums, since it allows free word-of-mouth advertising. Furthermore, additional information sources available via the mobile device must also be free of copyright (or use GPL licence like Wikipedia).

3.3.2 Interface and Device Design ("How?" or "Which way?")

Device and interface design play an important part in the acceptance and usability of a mobile application by visitors.

Usability

Even the best content is of no use if the visitor is not able to access it immediately. Visitors require an instantly understandable and easy to use interface. Gammon (1999a, 1999b, 2004) describes the difficulties with media installations in museums and the problems in using them. A common reaction of visitors if a media station does not provide an incentive in the first ten seconds is to loose interest quickly and leave it (Hornecker, & Stifter, 2006). A similar reaction has to be expected for PDAs. The simplest possible design [Also known as KISS: Keep It Simple and Stupid.] with the fewest options in combination with extensive usability testing with heterogeneous, real visitors is necessary before a device can be released for

public use (Naismith et al., 2004, p. 34; Petrelli, & Not, 1999). With formative evaluation and examination of log files (displaying visitor usage) a realistic picture of visitors' capabilities, requirements, and actual usage can be gained. Problems encountered by large parts of the visitors are possible and should not be underestimated. A useful feature might be to include different versions for different user types (e.g., a version for children, one with a reduced interface for people with low computer literacy, an audio guide version with a guided tour for people who do not want to interact with the device but require information). Special solutions for impaired visitors also exist; for example MUSEpad was designed and tested to serve user groups with different abilities (low vision, low hearing, mobility impairments) and of different needs by adapting content and output (Kirk, 2001).

User input still poses a problem in dealing with PDAs. While selections can be made with few buttons (cp. the Apple iPod design), extended user input (entering free text) is difficult. Without external keyboards visitor input is even more restricted and harder than at a media terminal. If visitors do not know in advance how to enter information by using the handwriting recognition software, it is unrealistic that they will learn it in the short amount of time they spend with the device. While mobile keyboards might be an option, they also require a table. In this case it would be easier to use media terminals that "recognize" the visitors (e.g., by PDA, RFID, or codeword) and allow them to give feedback or make contributions via the terminal. Visitors who left their email address for later access of the information collected in the museum might prefer to make contributions (e.g., to a Wiki) from their home computers. Audio commentaries might also be used since most PDAs are equipped with a built in microphone. However, they cannot be easily (i.e. automatically) analysed.

Visitor attention

While PDAs might greatly reduce the amount of distracting information labels in the exhibition, it also changes the visitor-exhibit relationship. This "lure of the screen"-concern

[It is also known as „heads-down“ phenomenon, describing the typical head position when visitors are engaged with a PDA (Exploratorium, 2005).], that screen-based devices may distract visitors from the exhibits, is an important issue (e.g., Walter, 1996). This can be partly avoided if textual output is given verbally per audio, leaving the eyes free to take in the exhibits (Proctor, 2005). Since this would cancel the advantage of easy content changes, software is necessary that transfers text to speech in decent quality. The function keys of the PDA and its touch screen would be used mostly to allow selection and to display pictures and videos that cannot be given auditory. Visual media should make an explicit relation to the exhibit (cp. Walter, 1996): The information presented can only be decoded if the visitor frequently looks at the exhibit to include important but missing points in the video/picture (“back and forthing”, Exploratorium, 2005). A related but complex solution is to use the screen as “magic lens”: The visitor sees the exhibit on the screen via the camera of the PDA. If the PDA is also able to recognize which object is displayed at the moment, it can augment it by additional information on the screen.

A PDA also changes the visitor-group-relationship: “Visiting a museum is a social occasion. Hardly anyone visits a museum alone” (Gammon, 2004, p. 49). But mobile guides are one-user devices that make them difficult to share. Small screen sizes and one audio output do not easily allow shared experiences with other visitors [This is a common problem of most media in museums: Most hands-on devices, media terminals and installations are conceptualised for a single-user even though groups are much more common (Gammon, 1999a; Kelly, 2000).]. Headphones that improve visitor-exhibit-relationship further increase this problem. The visit becomes an individual experience and cuts down social interaction (Wise, & Lawrence, 2001). Woodruff, Aoki, and Thorton (2001) suggest giving visitors the ability to eavesdrop on a companion’s audio guide and equipping visitors with only single-ear headsets to enable shared and individual activity. Providing only one PDA per group might assist the person carrying it in educating the whole group. On one hand such a solution would cancel all

advantages of personalized adaptation of information, but on the other hand information could be adapted to shared interests and shared characteristics of a group and thereby further support common ground (Clark, & Brennan, 1991). Kruppa et al. (2005) presented different content to different members of a group and encouraged them to exchange this information. Visitors' knowledge exchange might also be delayed until after the visit: Context-aware software might be used to collect data which information and exhibits members of the group have seen and match topics for discussion and links ones own information to the information ones visiting partner has seen. Learning trails or interest trails might also be used in this way.

Device Design

Besides, the interface the device itself requires careful planning. While some museums use commercial PDAs with a simple logo attached, other (especially larger) museums use special versions for museums. The later solution might help to avoid techno-fatigue of adult visitors (Gammon, 1999a), who associate computers with work settings and do not want to use them in their spare time. A PDA should be designed to fit to the exhibition and to look as little like a computer as possible (Hornecker, & Bartie, 2006). But such a museum-specific design might also decrease visitors' perceived familiarity with the mobile device.

Another issue is the handling of the PDA. If allowed, visitors usually take their bags and jackets with them into the museum. The PDA must be carried additionally and used while they are already carrying something else. When visitors want to engage with a hands-on-exhibit or use their hands otherwise, the PDA disappears in a pocket, sometimes until the end of the visit (cp. Exploratorium, 2005, p. Sec. 1:15). However, carrying the PDA as a "pendant" around the neck or like a wristwatch on the forearm might overcome this problem and leaves both hands free for interaction with the PDA and exhibits.

3.3.3 Technical Implementation ("With what?")

The heterogeneous group of museum visitors and the situation itself poses special requirements on the technical implementation.

Location-aware technology

Location-awareness is still the most important unresolved technical problem. Currently, there is no system with the necessary temporal and spatial resolution for accurate, fast and continuous positioning and content delivery that can – with acceptable financial and structural effort – be implemented in a museum (especially indoors). Table 3 gives a short overview of the commonly used location technologies (also see Hornecker & Bartie, 2006; Proctor, 2005). According to Proctor (2005), to ensure really accurate automated localisation, different positioning technologies have to be combined. Also, different settings require different location technologies (e.g., GPS cannot be used indoors, not all ceilings can be equipped with beacons). The required implementation further depends on the kind of location-information needed: Identifying a visitor only at exhibits is much easier than realising continuous visitor tracking. The technology will probably improve dramatically over the next few years, especially regarding RFID, which is predestined to be used to locate visitors, but currently does not offer the necessary range for unobtrusive and accurate localising. Even if the accuracy has the desired spatial resolution, the temporal resolution must also be high enough. Visitors seem to be frustrated by the latency in content delivery (Proctor, 2005). From a psychological point of view location-awareness seems to be especially full of potential in museums (cp. 2.1.1).

Table 3: Overview on location-aware technologies in museums

Location-Aware Technologies in Museums				
System	**Short Description**	**Major Advantages**	**Major Problems**	**Literature**
manual entering of position	Selection of exhibits by - typing of exhibit numbers - visual icons - sensitive maps most commonly used in the past and now	high accuracy if numbers relate to exhibit direct information possible simple and cheap usable in almost every setting	sensitive maps cannot be used as for navigation (visitors need to know their position to use it) can't be used to push information (visitors need to make an explicit action) visitor needs to do the work and has the cognitive burden	
infra-red	IR-beacon at exhibit, ceiling or wall	high accuracy (if visible)	low range interference by sunlight possible "line-of-sight technology" "requires direct intervisibility between device and tags" [footnote IR]	Benelli, Bianchi, & Diligenti (2000) Oppermann, & Specht (2000)
GPS	Global Positioning System via satellites build in or available via Compact Flash Card	no infrastructure necessary free service	low accuracy for commercial purposes (5-15m) not available/accurate indoors for approximate outdoor localisation only	Schmandt, & Marnasse (2004)
WiFi/WLAN	triangulation/trilateralisation with software (e.g. Ekahau Engine) identification of access point localisation also possible	uses common infrastructure (WLAN) approximate accuracy 1m	at least three base stations necessary at all times for triangulation accuracy depends on number and signal stability of base stations, architecture, distances, calibration, visitor density	Bahl, & Padmanabhan (2000) LaMarca et al. (2005)
Ultrasound	ultrasound beacons and ultrasound sender/receiver at exhibit or wall / ceiling	very high temporal and spatial resolution	extensive infrastructure necessary	Lonsdale et al. (2004) Randell et al. (2002)
RFID	Radio Frequency Identification uses radio waves to identify objects. Mostly this systems consist of chips, which can be "read" by a receiver	no line-of-sight is needed small, unobtrusive	short range (about 30 cm if reader is attached to CF-slot of PDA) additional power drain	Ni, Liu, Lau, & Patil (2004)
Bluetooth	triangulation/trilateralisation with software or single-point location	uses available PDA technology	low spatial resolution low temporal resolution additional power drain	Gonzalez-Castano et al. (2005)

[footnote IR: This is a serious problem – especially in crowded museums: Visitors can willingly or unwillingly cover the IR-port; other visitors can remain standing in front of the IR-beacon, preventing other visitors from accessing it (may misunderstand technology and think that they need a constant connection to the beacon); visitors do not leave their bags/backpacks at the entrance and may put the PDA in a bag, thereby making it "invisible" to the system.]

Stable and Fool Proof System

Visitors normally have low tolerance for systems that do not work perfectly (Proctor, 2005). Even if they think that they are responsible and do not know how to use the system, they will probably be dissatisfied with the PDA and pocket it for the rest of the visit. A frequent problem are unstable WLAN networks (Proctor, 2005) causing the device to loose information input/output or spatial position and frustrating users. Stability problems also cause extensive stress on the museum personnel, resulting in mistrust of the system, acceptance problems of devices, and reactance against its use.

Visitors, especially adolescents, might also be more interested in the device itself, trying to find out how it works or how to return to the operating system and explore the preinstalled programs. While lack in computer literacy might be overcome by a simplified interface, security features against tampering should also be implemented. The xpedeo-system of the Ueberseemuseum in Bremen, Germany, uses commercial PDAs whose program is specifically designed to prevent returning to the operating system. A loud alarm sounds if the SD-card is removed and the device automatically restarts the exhibit program if rebooted. While there is no perfectly secure system, it should be designed to be a too high a barrier for most visitors to tamper with. A device design that looks less like a commercial PDA and more like a part of the exhibition (making is useless outside of the museum due to its casing and form) is an idea worth pursuing. Some museums "overcome" this problem by resetting it after

every visitor (Wise, & Lawrence, 2001). Whether this is a lasting solution seems doubtful. An additional problem poses the use of an internal WLAN network, which might become compromised if a visitor gets unauthorized access to it via the device. While this worst-case scenario may be improbable, the danger of putting the museums CMS at risk should be considered and appropriate security features must be implemented.

Rugged Hardware

The hardware of technical devices in the museum is subject to high stress due to heavy use (Gammon, 1999a, 1999b). This stress is increased by the handling of visitors who are unfamiliar with the technology and whose behaviour borders on vandalism. Devices must be especially rugged and protected against visitor misuse.

4 Conclusion and Discussion

In this article we presented a field of research where psychologists, educational and computer scientists may benefit from each other: Mobile technologies in museums are of special value, if they heighten the educational, motivational, and emotional visiting experience, are innovatively designed, and run stable and smoothly. By working together interdisciplinary and exchanging results this goal may be achieved. We hope to advance research and practice in the context of mobile technologies in museums with our analysis of potentials and challenges from a psychological viewpoint.

Mobile devices offer a great potential for use in museums and other informal learning settings: They are bridging the gap between the visit itself and the life of the visitor. Visitors can prepare their visit and can access this information during the visit. Back at home, they can follow-up on interesting topics. Information during their visit, adapted to their interests, prior knowledge, and other characteristics, can be integrated into their existing knowledge structures. They not only serve mental knowledge structures but also – since the information is available digitally and thus highly flexible – external memory structures like print-outs,

computer files, emails, or web resources. In addition to these benefits of mobile media, they can be realized very unobtrusively and consequently do not disturb the visit, the aura of the object, and the social experience. Borders between virtual and physical museum vanish, combining the best of both worlds.

The museum itself retains its unique strength: the authentic exhibits. Objects remain the prime focus and are free from distractions like labels, sounds, multimedia displays, or visible technology at the exhibit itself. Still they are accessible to different kinds of visitors in their uniquely preferred way.

Most of these potentials are worth pursuing and possible to implement with today's technology. However, some challenges remain to be addressed, most importantly realising continuous position tracking.

From a psychological point of view it will be very interesting to find out whether and under which conditions these advanced mobile devices are really helpful in informal settings, for example the role of adaptive information (see Mayr, 2007, at this conference) or interest (see Wessel, 2007, at this conference).

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