Navigation Support for Mobile Learning

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Abstract
Mobile learning exposes learning to the natural environment. If this environment is large, the learners have to navigate to find the learning objects or to explore the environment. Current mobile learning systems provide only minimal navigational support. Prior studies report that conventional pedestrian information systems are not suited to mobile learning, as the learners focus too much on the navigation system. In this paper we analyze issues in navigational support and provide evidence for the lack of support in current systems. Then we propose and evaluate how mobile learning systems can not only provide better navigation support, but also prevent the focus problem. The tested concepts include using an aura to visualize the accuracy, using history visualization for orientation and browsing support, and using information pull to focus more on the environment. Recommendations for further research conclude the paper.

1. Introduction
Many innovative mobile learning projects take place in the physical context [1]. Here the place of being is relevant to the learning issue. It could be a botanic garden, where something is learned about the flora and fauna [2], a butterfly farm [3], where butterflies are studied, a museum [4, 5] or like in our project, a university where new students learn to work and live on a campus [6].

These projects have in common that a learner is acting and learning in an unknown environment. Typically, the learner works on his own to explore the environment, being guided only by a task description and the mobile information system. So these systems need a kind of orientation or navigation support.

Many times learners cannot use a traditional pedestrian navigation system because it hinders learning [7]. It would have the same effect as driving with a car navigation system. Typically, one would not build a cognitive map\(^1\) of the driven route because the mental effort would be “outsourced” to the navigation system. Most drivers would not be able to drive the route back without the navigation system.

As the mobile learning community is aware of this problem, the pedestrian navigation systems are not used, and only basic orientation support is given. This, however, leads to another trap. The bad navigation support requires too much mental effort and distracts too much focus. Instead of learning something about the environment, the learner has to handle the complex and irritating orientation system. It is more or less the same result as using a pedestrian navigation system: the learner learns almost nothing about the environment. This leads to our research question of how to design an adequate orientation support system for mobile learning that does not harm learning.

This paper discusses ways to overcome this dilemma by reporting on six years of research with a mobile learning game, the mExplorer. First, this paper discusses the specific differences between traditional pedestrian navigation systems and orientation support in mobile learning (section 2). Next, the research gap is shown in the literature review (section 3). After this, we present the mExplorer system (section 4). Following are the results of four field tests and suggestions for improving orientation support in order to improve learning (sections 5 and 6). The paper ends with a summary and an outlook of further research (section 7).

2. The Orientation Support Dilemma in Mobile Learning Systems

Mobile Learning is not just classical classroom-based learning broadcast to mobile devices, but rather personalized, learner centered, collaborative, ubiquitous and often informal learning [9].
Frequently learning is embedded into a physical context. This requires knowing where you are ("orientation") and where you need to go ("navigation").

There are importance differences between pedestrian navigation and the navigation of mobile learners. The main objective traditional navigation system for pedestrians is to guide a person to a specific location. Normally, the user needs to know the fastest (or easiest) track. Typically, it is not important to build a cognitive model of the area for later orientation without the navigation system. The focus is on guidance on the track or on the track description itself [10-13].

The goals mobile learning systems in the physical context focus on learning aspects and thus the spatial memory created. Early Research in psychology stresses that learning from a map and learning by direct experience lead to different functional characteristics of spatial memory [14]. The size of the map and the size of the area the user navigates determine the quality of the spatial memory. However, later research reported no significant difference in performance between map and immediate learning [15], if exposure to the map is sufficiently long. Aslan et. al. [7] compare the learning success of pedestrians using a navigation system and a traditional map. They show that pedestrians with a navigation system do not build up a mental map to accomplish survey knowledge. It is similar to using a car navigation system. One just follows the instructions of the system, but there is no build up of a mental model. As pedestrian information systems tend to be simple, they are unlikely to create an information overload [16] themselves. They rather appear to induce lazyness or to capture the attention. None of this well-cited work builds on a theory of spatial memory.

Different mobile learning systems have different learning goals. The analysis of our own mExplorer project [17, 18] and the 38 projects in the physical context identified by Frohberg et al. [1], show the following general learning goals which could be targeted by mobile learning systems. These are to learn something about the:

1. **Objects in the environment**: The learners’ target is a specific object in the environment, but not the environment itself. A typical example is a museum, like in the Tate Modern Multimedia Tour Pilot [19] or Myartspace project [20]). Here, the learning system guides the learner through the museum and shows him specific exhibits, depending on his interest or learning goals. The learner, of course, learns something about the exhibited paintings and not about the museum itself.

2. **Behavior in the environment**: The learning focus is on a behavior in the environment. An example, is when one learns Chinese in Taipei [21] with the support of a mobile learning system. The mobile learning system helps to understand the displays in the shops, the road signs or the interaction with the people on the road. It also provides guidance for good learning places where a lot of interaction with the environment is possible. However, it is irrelevant whether one uses this in Taipai or Beijing. It is only necessary that one is in a Chinese speaking environment.

3. **Environment itself**: In this type of learning goal, the environment is really in the center of the scenario. Apart from the behavior, the environment is also important. For example, in our mExplorer project [17] a new student learns navigating and “living” on the university campus by exploring the campus. In the Ambient Wood project [22], students learn about the ecosystem of a forest by exploring it. The system has to guide the learner to the specific locations in the environment, support him in his exploration, teach him the necessary behavior or processes, and familiarize him with his surroundings.

The more environment specific the learning goals are, the more the requirements differ from the requirements of a traditional pedestrian navigation system. If one only has the goal of bringing a person to a specific object in an environment, maybe one could use a traditional pedestrian navigation system. But in very environment specific mobile learning system there is a lot more to consider than just bringing a person to the right place. As described above, the learner needs to be familiarized with the environment.

But orientation support cannot be completely omitted. The learner is typically in a completely new environment. If there is no orientation support and additional guidance, the learner will only see fragments of the environment and its specific behavior. Also, the sample of fragments will be based on chance. In the worst scenario the learner gets lost.

This is the dilemma in mobile learning. Orientation support is necessary, but traditional navigation systems cannot be used.

**3. Analysis of mobile learning systems**

Our literature review (see below) shows, that the typical way to overcome this dilemma in mobile
learning systems is to give the learner a digital map and show him his current location.

With the mExplorer (which in the first version also uses the normal dot on the digital map) we observed this behavior many times. In several field-tests (see [23-25]) users told us that the navigation support was suboptimal. To optimize our own orientation support, we looked at other mobile learning projects in order to see what they were doing.

In Frohberg et. al. [1] all relevant mobile learning projects until 2008 were critically reviewed. and 38 projects situated in the physical context were identified. These projects were re-analyzed regarding their orientation support for this paper (see Table 1 – the mExplorer is excluded in the table as it will be analyzed in detail later).

We checked whether the system offered digital orientation support. We did not count a teacher or a professional guide as orientation support. The next check was whether they had area-wide positioning or not. This is relevant for systems which have the environment or the behavior of the environment as a learning goal (see section 2). In this case, the learner explores an unknown and typically large and complex environment and needs area-wide guidance and orientation support. If not, the danger of getting lost is quite high. Additionally, we looked for the use of an underlying technique.

<table>
<thead>
<tr>
<th>Project</th>
<th>Orientation Area-wide P.</th>
<th>Technique</th>
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<tbody>
<tr>
<td>Ambient Wood [22]</td>
<td>X</td>
<td>FM Pingers</td>
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<tr>
<td>Bird Watching Learning System [26]</td>
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<tr>
<td>BodyLearning [27]</td>
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<tr>
<td>Butterfly Watching Learning System [3]</td>
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<td>Caerus [28]</td>
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<td>Clls [21]</td>
<td>X</td>
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<td>CLUE [29]</td>
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<tr>
<td>CropViewer [30]</td>
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<td>Environmental Detectives [31]</td>
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<td>eSchoolbag [32]</td>
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<td>Exploratorium [5]</td>
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<td>Garden Explorer [33]</td>
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<td>Genius Loci [27]</td>
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<td>Gipsy [30]</td>
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Table 1: Orientation support in mobile learning projects

Twenty one of the analyzed 37 projects provide orientation support. And only seven have area-wide orientation support. Most other projects use tagged physical objects to identify a point or location of interest. Users are free to move around and are guided by these interesting objects. With this kind of system it is difficult to reach higher learning goals other than learning about specific objects in the environment.

On the technical side, most projects use RFID for object tagging or a GPS for continuous outdoor positioning. Some projects use wifi-based positioning methods, such as the ekahau engine.

But the most unexpected result of all was that there was no orientation support that went beyond the dot on the digital map. All these results lead to the conclusion that the common way to support navigation is the dot on a digital map. But as described above, this kind of orientation support is inadequate and, even worse, hinders learning.

Based on several field tests and the derived experience, we propose new ways for assisting orientation support for mobile learning (section 5). The next section first presents the mExplorer System.

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3 Area-wide positioning means that in every location in the environment the current position of the user can be determined and displayed on the system.

3 See www.ekahau.com
4. The mExplorer

The mExplorer is an orientation rally which is used to familiarize new students with the university campus. The rally leads participants through an area with several tasks to accomplish at specific spots. The students play in small teams against one another, each team having a handheld computer.

The handheld device shows the current position of the team on the digital map of the university. When the team enters a building, the outdoor map switches to an indoor map of the building that the team has just entered.

During the orientation rally each team receives different tasks that refer to important places. The students have to find relevant places, such as the library, the cafeteria or the laboratories. These locations are also marked on the digital map. At each location, they have to perform a typical task (find a book, have lunch, etc.) for which the handheld device supports the task execution (e.g., providing required information).

The learning goals, apart from the familiarization, are building a cognitive map of the environment and learning the processes, which are important for new students.

During the game the player has orientation support through the mExplorer client. Figure 1 shows the screenshot of the orientation screen, which has several features described in this section. The orientation relevant features are discussed in detail in the results section (section 6).

Figure 1: The optimized orientation support of the mExplorer

In the center of the user interface is the digital map of the whole university campus. It shows the current position of the player, visualized as an orange dot. Around the dot is the aura, which visualizes the inaccuracy of the positioning system.

The red arrow on the aura visualizes the viewing direction, which means that the player is currently looking to the right side of the map. The line behind the players’ own position depicts the walking history.

Additionally, there are the positions of other players on the map. In order to avoid lazy collaboration and keep the players moving, we introduced a hunting rule. Each playing group (typically groups of two walk together) is “wolf” to one competitor and “sheep” to another. The map also provides information about two different points of interest, visualized as two circles with an “i” in it. The red circle is a point of interest, which is annotated with a media file, like audio, photo or video; the blue one is only annotated with plain text.

On the bottom of the user interface is the button bar, which is used to control the GUI. The first button on the left side is the update button, which is pushed to get the newest information from the mExplorer-Server. Only when pressed, will the mExplorer update client with the digital map, the positions of the players and the status information about the game.

The other buttons lead to several other parts of the interface that are used for tasks description, chat, hunting or annotation. But these parts are not relevant for this paper. A complete description of the interface can be found in [18].

5. Field tests

Between 2003 and 2007 there were eight trials of the mExplorer system. A comprehensive discussion of the methodology and the experimental design can be found in [18]. Navigation issues were explicitly tested in spring and autumn 2004 (published in [24]), in autumn 2005 (published in [54, 55]) and in autumn 2006.

The first two trials with 22 (field test one) and 149 (field test two) students tested general orientation support with the digital map and the aura in the learning scenario. The third field tests took place in Australia with eight students. Here the mExplorer system was not tested in the learning scenario on a university. Instead, it was used to support tourists in reflective exploration of a touristic hotspot. In this context the path history was tested. The experiment was set up in a way that required the tourists to explore the environment. Thus the learnings goals were very similar to our University scenario. The

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4 One of the authors insists that it looks more like a duck
results of these three field tests were already published. Therefore, this paper will only summarize (sections 6.1 and 6.2) the results relating to the orientation support dilemma.

The last field test (field test four) focused on novel approaches to orientation support. It was undertaken at the beginning of the winter term 2006, and took place at the Irchel campus of the University of Zurich. We asked the new computer science students from the introductory course if they wanted to join an orientation rally to see the campus. 49 Students participated in the field test, of whom 12.24% were female. 53.19% were new students in the first semester. All other students were older students who were enrolled in computer science as a minor course.

The field test was primary focused on orientation support to overcome the orientation dilemma. In this way, the students had only to fulfill three different tasks. The location of this tasks was selected in such a way that, if the places were visited, the students would have seen the whole campus. After the tasks were completed, the student were asked to explore the campus on their own, and were asked to mark locations of interest on their pda. The game finished after approximately 60 minutes. After the rally each player was given a questionnaire.

In this game all participants were supported with the aura (see section 6.1) and the visualization of their walking history (see section 6.2), which were already in the former trials. Apart from this support, we tested two new kinds of orientation support. On the one side we added an arrow to the system which visualized the point of view (see section 6.3). 24 participants played with this option, 15 did not use it. We also tested a version with information pull (see section 6.4), and 19 students played with information pull and 20 with information push. There were a further 10 players who played an analog version of the game, but their results are not relevant for this paper.

6. Results

The following section describes the four solutions we tested to overcome the orientation dilemma. These four solutions go beyond the traditional dot on the map solution. The results to every solution are presented in three or four steps. First, we describe the concrete problem we want to overcome with the solution. Next, we describe the solution itself, and finish with the presentation and interpretation of the results. In some cases we propose further improvements based on the results.

6.1. Using an aura to visualize the accuracy

Problem: The mExplorer uses the ekahau positioning engine for indoor positioning. This wifi-based method has an accuracy of three to five meters in areas where the PDA can connect to four or more access points. If there are fewer access points, the inaccuracy increases. Additionally, there is a lag of 1 to 5 seconds before the current location reaches the pda and can be visualized. If the learner is moving fast, the accuracy decreases. The effect is that the visualized ‘own’ position is not there where it actually should be.

The inaccuracy can irritate a person exploring the new environment, especially when indoors. It is much, more difficult to orientate inside a building because the proximity of walls prevents an overview. Every floor looks like every other. Users always have to check whether the system is giving the correct position or not. This adds a mental load in addition to the normal workload. This results in the learner totally concentrating on navigation. This can easily lead to huge mental overloading and no mental space left for learning.

Solution: Currently, this inaccuracy cannot be solved technically because physically wi-fi cannot be improved, and more accurate positioning systems, such as ultrasound based positioning, are too expensive for bigger buildings.

Thus, instead of improving the accuracy, we support the player by visualizing the inaccuracy with an aura around his position. In this way s/he can handle the inaccuracy because it replaces the trust in the positioning system. Additionally, it minimizes the “solution space” of the actual own position. Both effects reduce the mental effort that the user has to spend on orientation, and allows mental space for learning.

Results: The observation in the trials shows clearly that with the aura the orientation is much easier than with the normal dot. 69 students in field test two rated the navigation functionality of the mExplorer with the aura with 4.58 on a scale of 1 = very bad to 5 = very good (for detailed results see [24]).

Further improvements: In addition to building in the area wide positioning system with the described accuracy, a possible solution is to use object tagging to improve the accuracy on very important places where the learner really needs very good accuracy. In this regard, some of the mobile learning systems with object tagging have good results.
6.2. Using history visualization for orientation and browsing support

Problem: Navigation is typically based not only in the current position, but it also covers the prospective and past paths of the user. People find it helpful to see where to go and where they have come from while navigating. It helps them to synchronize the observed surrounding if they have the abstract representation on a map. Traditional navigation systems use this effect and show the user a line on the map, indicating where to go next. But as described above this, navigation support hinders learning (see section 2). This means orientation support cannot use this positive effect of the prospective walking away.

Solution: Instead of using the prospective, we use the past path of the learner. We visualize the walking history as a red line behind the user (see Figure 1). This helps the learner (in the same way as the prospective path) to align his surrounding with the map. Additionally, it supports learning while exploring an environment. The learners see where they have already gone, and in this way, know which part of the environment has already been explored. This gives a better understanding of where to go or what to do next. Both effects enhance learning.

Results: The field test in Australia (field test three) indicated that this kind of history visualization is helpful for exploring new environments. The users rated the usefulness of the history function with 4.375 of 5. We observed that users used the path history for aligning the map with the surroundings. Also, none of the users visited a location twice (for detailed results see [54]).

A design challenge is to determine the time that the history needs to cover. Are the last three minutes enough? Or should it cover the last hour? The time depends very much on the learning scenario and the size of the environment. Our results shows that tourists who want to explore a wider area, such as a historical city center, are very happy with 30 minutes.

The same length of time was inadequate for the mExplorer game at the university. In field test four we observed that students quickly turned off this function because it painted all buildings red on the digital map, and they could not see anything. (Here the history time of about 30 seconds would be much better for them.)

Further improvements: The described positive effect could possibly be improved by integrating a “fog of war.” This is an element in many computer games where players have to explore virtual environments. Although they have a map of the environment, only the parts they have already explored can be seen clearly. The other parts are completely black or blurred. In combination with a very short path history, this effect should be helpful.

6.3. Using an arrow to visualize the line of sight

Problem: In all field tests with the mExplorer we observed the map rotation problem [56]. While navigating through the new environment the participators stand still every few meters and rotate the digital map on the PDA to bring the map in line with the surroundings. Typically, people are better in orientating with a map if the map is aligned to the line of sight.

Solution: The first attempt to compensate the problem was to rotate the digital map in the line of sight. But because of the low CPU power of the PDA, this could not be done in real-time while running the mExplorer client with all game-necessary functions [18].

To avoid digital map rotation, we added a red arrow which visualizes the line of sight (see Figure 1). On the technical level, this was done by adding an electronic compass to the PDA.

Results: In both field tests in 2004 (field test one and two) players asked for compass support to show the line of sight (see [24]). But at this point of time we were unable to do this due to technical reasons.

For the fourth field test in 2006 we used a sensor board, which was designed by Peter Vorburger. The problem was the very unstable serial connection to the PDA. This connection was manually brazed on the battery and on the serial port of the PDA. In the field tests this connection was broken several times. The mExplorer and the PDA reacted with a slowing down or a freezing. Also, the processing of the sensor data took a lot of CPU power which, in turn, caused a dull user interface. In this way, the results were affected by the technical problems.

We asked the participants how helpful the visualization of the line for orientation support was. The rating was 2.83, which means that it was not very useful for most players. But the histogram (see Figure 2) shows that the red arrow splits the player. There are players who like the visualization and some who do not. There are also some small influences on fun and orientation. In comparison to players without the red arrow, the players with the visualization had more fun (4.00 to 3.73) and could orientate better.

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5 Points on a scale from 1 = not at all to 5 = very much, N = 8

6 Points on a scale from 1 = very useless to 5 = very useful, N = 24

7 Points on a scale from 1 = very few to 5 = very much, N = 39
(3.46 to 3.27). But these differences are not statistically significant.

![Figure 2: Rating of the visualized of the line of sight](image)

**Figure 2: Rating of the visualized of the line of sight**

The observation of the players shows that most player had massive technical problems with the attached sensor board. This was also shown in the feedback in the open feedback part of the questionnaire, in which the participants named the three most distracting aspects of the mExplorer. 22 out of 39 players mentioned the dull interface, and 8 mentioned the bugs.

In summary, these technical problems overshadowed the potential usefulness of the red arrow. A few students who rated the arrow as very good ignored these obvious problems and indicated liking the idea itself. At this point in time, we do not have quantitative data to support this. Overall, we believe it is a good idea to support orientation, if the sensor is stable enough not to hinder the rest of the system. At the time of writing, we notice that the new Apple Iphone includes a compass. Thus, we expect basic direction support to be included in the next generation of mobile learning systems.

### 6.4. Using information pull to focus more on the environment

**Problem:** Another general problem in the field of navigation support is focus distraction. Instead of exploring, the environment players are constantly looking at the PDA, and largely ignore the surrounding environment. This hinders not only learning, but is also very dangerous. We observed several times that players were bumping into doors, pillars or into other persons. The animated client with constant new information distracts the focus of the user. Therefore this phenomena was named a focus problem [57].

**Solution:** To reduce or avoid this problem, we integrated an information pull mode. In contrast to the information push modus, which provides real time updates, in pull mode the player has to press the update button to get the most current information. In this way, the player always has the needed information without the distraction of unnecessary information. Also, the noisy interface with constant animations is calmed. In this way the pull mode should lead to a better focus on the environment, as well as the learning goals.

**Results:** In the fourth field test in 2006, we compared the behavior of players with pull and players with push information. In the questionnaire we asked them how often they looked at the screen of the PDA. The 19 players with information pull rated this answer with 5.32 on a scale of 1 = very rare to 7 = very often. The 20 players rated this question with 5.85. A two-sided T-Test shows that this difference is statistically significant (sign. = 0.04).

We also asked the participants how much they were distracted from the environment through the PDA. On a scale of 1 = very few to 7 = very much, the players with information pull rated the distraction with 3.58. Players with information push rated the question with 3.89, slightly worse. But this small difference is not statistically significant.

Both ratings indicate that pull mode may lead to less distraction, but the differences are small. The main question is whether this difference will lead to better exploration or learning. The answer is yes. In the field test we asked participants to mark new important or interesting places on the digital map. After the game the players were asked to mark the places they remembered on a paper map. We compared the marked places of the new students of the first semester. Students of higher semesters were excluded from this comparison because they typically know all the important places on the campus. For the comparison of information pull and push, we counted the markings on the paper map.

The histogram in Figure 3 shows the difference between players with information push (1 - above) and pull (2 - below). The 12 players with information pull could remember on average 7.33 points. The best player could actually remember 13 places. The 9 players with pull information could, on average, only remembered 5.00 places. The best player here remembered 9 places. This huge difference is statistically significant. A one-sided T-Test shows a significance of 0.034.

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8 Points on a scale from 1 = very bad to 5 = very good, N = 39
This results show that the switch from information push to information pull is a useful one. The players are more focused on the environment and learn more about it. The solution is not perfect because the results from the questionnaire and the observation show that the participants are still looking too often at the PDA. But it is a good first step in eliminating the focus problem.

Further improvements: For further reduction of the focus problem, please see an in depth discussion in [57] where we propose several other improvements in addition to the usage of information pull.

7. Summary and further research

We have shown four design recommendations for improving orientation support in the area of mobile learning:

1. Use an aura to visualize the accuracy of the positioning system to support orientation.
2. Visualize the walking history in dependency of the learning target and location to support awareness of the current position.
3. Use a visualization of the line of sight to reduce the map rotation problem.
4. Use information pull instead of information push to reduce the focus problem.

Pedestrian navigation support from the HCI research area cannot directly be applied to mobile learning if exploration is the objective. But this should not mean that learners are only supported with a dot on a digital map, as it is done in most mobile learning projects (see section 3). This kind of very basic navigation support harms learning too much. By using the four design recommendations, the learner should be much better supported in his orientation process, but without the negative effects of a traditional pedestrian navigation system. However, this is only the first step. Further research should improve orientation support especially for the needs of mobile learning.

Further research should target two different areas. On the one hand, the focus problem is not completely solved yet. Special design techniques, such as the explicitly designed focus switches, appear to be the right way here. The goal is to bring as much focus as possible from the technology and the mobile learning system to the environment and the learning goals.

On the other hand, the navigation support itself should be enhanced. Even if the results in the HCI research area cannot be adopted directly because they are based on the needs of pedestrians and not learners, they may still be a good starting point. Like the path history, the basic idea of which came from a traditional navigation system, the results have to be reviewed and adopted to the field of learning. But the first question in adopting should always be: “Does this kind of technology support or prevent learning?”

In our opinion, the potential of adoption from the HCI research area is quite high. There are good results with photo support [10], sound support [11] or the usage of public displays [58]. This kind of additional information can be used to give specific orientation support in areas which are very relevant for learners, or where they need additional guidance. Maybe some futuristic ideas with haptic input from shoes [13] or belts [12] could also be relevant because this kind of information does not absorb as much focus as the traditional systems on PDAs. Overall, there is a lot to do in the area of navigation support in mobile learning.

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