Unearthing Invisible Buildings: Device Focus and Device Sharing in a Collaborative Mobile Learning Activity

Marcus Winter
University of Brighton, UK
marcus.winter@brighton.ac.uk

Lyn Pemberton
University of Brighton, UK
lyn.pemberton@brighton.ac.uk

Abstract
Recent research has identified excessive focus on the mobile device itself as a serious problem in mobile learning. Various recommendations have been formulated for the design of mobile learning technology and pedagogy to reduce device focus and foster students' engagement with peers and with their environment. This paper describes how some of these recommendations have been implemented and extended in the design of Invisible Buildings, a mobile collaborative game-based activity for schoolchildren. It reports the results of an empirical evaluation of the learning experience with primary school children, focusing on students' engagement with their social and physical context during learning activities, and providing insights into their behaviour and strategies with respect to device sharing.

Keywords
Mobile Learning, Device Focus, Device Sharing.

1. INTRODUCTION
Over the last decade our understanding of mobile learning has shifted focus from mobile devices and technologies to learner mobility and the social practice it enables. A key concept in this new understanding is context, created by the learner in interaction with others, with their surroundings and with the tools they use (Kukulska-Hume et al., 2009). Recent research, however, has pointed out that in many mobile learning projects where students share a mobile device to complete tasks collaboratively, their engagement with the environment and with each other is reduced significantly as they focus too much on the shared mobile device (Eliasson et al., 2010; Göth et al., 2006).

To address this problem, a number of design guidelines for mobile learning technology and pedagogy have been proposed. From an HCI perspective, where device focus and related issues in mobile computing have been researched for some time, efforts are generally aimed at reducing the cognitive load for users when interacting with the device, for instance by simplifying interaction screens (e.g. Pascoe et al., 2000) or balancing visual interaction with haptic or auditory feedback (e.g. Brewster, 2002). More holistically, Göth et al. (2006) advocate a mobile phone metaphor (as opposed to a small screen metaphor) for the design of mobile applications, which takes into account the specific use context, hardware characteristics and network requirements of mobile devices. From a pedagogical perspective, recommendations include assigning learners dedicated roles that require negotiation and coordination in collaborative learning situations, conceptualising mobile devices as tools that support learners in completing activities (as opposed to controlling and structuring the activity) and integrating teachers and support staff into mobile activities to scaffold learning and keep learners focused on the task (Eliasson et al., 2010).

The following sections describe how device focus and the related issue of device sharing were addressed in a collaborative mobile learning activity known as Invisible Buildings. We explain how some of the recommendations in Eliasson et al. (2010) were implemented and further extended, report on the empirical evaluation of these measures and conclude with a discussion of the findings.

2. INVISIBLE BUILDINGS
Invisible Buildings is a cross-curricular whole-day learning experience integrating outdoor mobile location-based games with complementary indoor classroom-based activities for primary school children aged 9-10 years. The learning experience is based on the discovery and excavation of an imagined Roman Villa beneath the school grounds and links to a wide range of curriculum subjects.

The learning experience uses custom-made mock-up tools derived from authentic archaeological practice, with integrated GPS-enabled smartphones used to discover and excavate virtual objects, together with a related project website that shows these objects as they are “found” in the school grounds and holds additional resources with background information relating to the objects and the wider project for indoor activities. The children’s activities are coordinated and motivated by a professional actor presenting himself to students as an archaeologist.

The project is structured into three outdoor activities in which students collaborate in teams to uncover virtual objects and structures in the school grounds, and alternating indoor activities where pupils reflect on their outdoor experience, discuss the meaning and implications of found objects and prepare their next steps outdoors.

Together, these activities form a chain of discovery, reasoning and further action (Figure 1) that ultimately leads them to uncover a virtual Roman Villa beneath their school grounds, a model of which they can then explore in the concluding indoor activity.
In order to keep group sizes manageable and optimise use of the available equipment, classes are divided into two halves which alternate in completing outside / inside tasks. For outdoor activities, each group is then further divided into teams of four pupils each, who stay together for the whole day and collaborate in each learning activity.

3. DESIGN ASPECTS

3.1 Dedicated roles

Eliasson et al. (2010) suggest using two or more mobile devices with different roles in a team, which implicitly assigns different roles to the students using them. *Invisible Buildings* uses only one mobile device per team. However, it defines dedicated roles for team members in each task, which are explained to students in detail before they begin their outdoor activity (Table 1).

Table 1. Roles in each team for the different tasks

<table>
<thead>
<tr>
<th>Task 1: Metal Detector</th>
<th>Task 2: Geo Phys</th>
<th>Task 3: Dig</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Controller</strong></td>
<td><strong>Controller</strong></td>
<td><strong>Controller</strong></td>
</tr>
<tr>
<td>Control the tool, interact with mobile device</td>
<td>Control the tool, interact with mobile device</td>
<td>Control the tool, interact with mobile device</td>
</tr>
<tr>
<td><strong>Stopwatch</strong></td>
<td><strong>Cones</strong></td>
<td><strong>Helper</strong></td>
</tr>
<tr>
<td>Measure time</td>
<td>Put down cones to mark outlines of floor plan</td>
<td>Secure boring head in position (inside cone)</td>
</tr>
<tr>
<td><strong>Hooter</strong></td>
<td><strong>Hooter</strong></td>
<td><strong>Helper</strong></td>
</tr>
<tr>
<td>Alert archaeologist when objects are found</td>
<td>Alert archaeologist when wall / line is found</td>
<td>Push digger lever</td>
</tr>
<tr>
<td><strong>Notes</strong></td>
<td><strong>Notes</strong></td>
<td><strong>Notes</strong></td>
</tr>
<tr>
<td>Take notes, make drawings of found objects</td>
<td>Take notes, make drawing of floor plan</td>
<td>Push digger lever</td>
</tr>
</tbody>
</table>

In order to give each team member an opportunity to control the main tool for the task and interact with the integrated smartphone, roles are swapped after a certain time when the archaeologist gives the agreed signal.

Auxiliary tools were introduced for each supporting role to emancipate team members in relation to the main tool controller and accentuate their specific purpose in the task. These tools included an electronic stopwatch to measure time, a hooter to notify the archaeologist when objects were found, a set of plastic cones to mark the outlines of the Roman Villa and a notepad to take notes and make drawings of found objects (Figure 2).

Based on research into conflicts and competition between children over shared resources in co-located collaboration around a tabletop (Marshall et al., 2009), it was hoped that these auxiliary tools would reduce interference from students in supporting roles with the device controller, as they add weight to their roles and encourage independence.

3.2 Mobile devices as tools

In order to avoid students being pushed into a passive role by mobile applications that structure and control the flow of learning activities, Eliasson et al. (2010) suggest approaching mobile devices as tools and utilising their inbuilt sensors to complete activities. This idea was further extended in *Invisible Buildings* by integrating the smartphones into mock-ups of tools used in authentic archaeological excavations, including a metal detector, geo-physical H-frame, and a digging instrument.

Conceptually similar to commercial products like Mobile Art Lab’s *PhoneBook* (*PhoneBook*, 2010), which embeds a smartphone into a physical children’s book and thereby reduces the mobile device to an interactive image in the book that changes content when pages are turned, and to game peripherals for the Wii controller (Figure 3), which turn the controller into a physical tool with similar ergonomic qualities to the real-world tool they represent, it was hoped that the integration of smartphones into mock-up tools emphasises their specific purpose in each learning activity and creates a more “life-like gaming experience” (Burrill, 2010).
In order to make the tools reusable and light enough for children to carry, they were composed of standard lightweight plastic waste pipes, bends and couplings that could be easily re-configured into the next tool in-between the learning activities. The smartphones were strapped into a small open plastic box fixed to the tool handle in order to protect the device and reduce daylight glare (Figure 4).

The mobile devices ran different applications for each outdoor task. The applications used the smartphone's inbuilt GPS receiver and network capabilities, and provided a task-specific touch-screen interface designed to look like an authentic tool (Figure 5). These measures reduced the smartphone to a mere user interface for the mock-up tool and helped to further enhance the tool's credibility.

3.3 Integrate teachers and support staff
Eliasson et al. (2010) point out that the involvement of teachers and technology personnel in mobile learning activities can scaffold students' learning and help to keep them focused on the task instead of the device. Taking this into account, all adults involved in Invisible Buildings played a role in the project and a professional actor was introduced to play the part of an Indiana Jones-style archaeologist. Teachers were responsible for logistical issues (e.g. dividing classes, forming teams, etc.) and in addition provided technical and subject related support. Technical personnel and research staff provided technical support and helped to keep students on task through guidance and encouragement. The archaeologist directed operations (constructing the narrative, introducing activities, explaining tools) and was the main contact for students to discuss subject issues.

3.4 Encouraging face-to-face collaboration
Instead of building collaboration directly into the mobile application and thereby forcing students to collaborate through the device, Eliasson et al. (2010) recommend placing collaboration outside the mobile device: this can increase face-to-face discussions between students and thereby support learning. This point was addressed in the project by using the mobile devices as tools only and leaving it to teachers and the archaeologist to structure and control the learning experience. Face-to-face collaboration between students was expected when students negotiated directions and locations to probe and when they discussed the meaning of found objects. Indoors, teacher-led discussions were planned for students to reflect collaboratively on their outdoor experiences.

4. EVALUATION
Invisible Buildings was evaluated over two consecutive days with two mixed gender classes of primary school children aged 9 to 10 years. Overall, 53 children took part in the study. The data analysis and evaluation were carried out by usability experts from the Interactive Technologies Research Group at the University of Brighton.
4.1 Ethical Considerations
With respect to the involvement of underage volunteers in the study, ethical issues were considered before and throughout the evaluation. Based on Anderson's (1990) guidelines regarding volunteers in research projects and Burgess’ (1989) discussion of ethics in educational research, specific considerations included collecting data anonymously and not making it available to third parties, informing pupils and their parents about the context and purpose of the study and pointing out to them that they could withdraw at any time without giving a reason. A consent form was distributed before the event, and pupils and their parents had an opportunity to discuss details with the supervising teacher.

4.2 Data Collection

4.2.1 First-person video observation
In order to record interactions from the user's point of view and obtain a contextualised view of the device screen, the device controller in a selected team of students wore a head-mounted camera fixed on a baseball cap, together with a microphone attached to his/her outer clothing and a carrier belt holding a miniature video recorder and energy supply. As pupils swapped their roles to allow everyone a chance to interact with the smartphone and mock-up tool, the camera cap, microphone and belt were transferred to the next student with the help of a researcher, so that the head-mounted camera always had a direct view on the mobile device and would record all user interactions.

4.2.2 Third-person video observation
To complement the head-mounted camera view, one researcher accompanied the same group of pupils with a handheld video camera to record video material from a third-person perspective. In addition to documenting whole-group interaction and interaction between groups, the material gave a useful second perspective on critical situations, which helped researchers during the analysis to better understand these situations as a whole. Indoor activities were recorded with a static camera placed in the classroom.

4.2.3 Questionnaires
A questionnaire was administered after each outdoor task when pupils returned to the classroom, to collect immediate feedback on the learning activity. The questionnaire included a closed multiple choice rating relating to the outdoor activity with categories, terminology and pictograms derived from the Problem Identification Picture Cards (PIPC) developed specifically for usability evaluations with children (Barendregt et al., 2008). In addition, the questionnaire had space for open comments where pupils could qualify their choices and give further feedback.

4.3 Data Analysis
The video material was evaluated by a panel of three usability experts from the University of Brighton. The panel watched the recorded video material for each activity, and critical scenes were repeatedly reviewed as required to better understand the issues at hand. Notes were taken during the screening and compared and discussed after each session. While the video analysis employed an emergent coding scheme and had no pre-defined themes to look out for, the experts were particularly interested in aspects of device focus, device sharing and collaboration between team members as well as ergonomy and usability problems with the equipment and mobile devices.

The questionnaire analysis involved aggregating the PIPC rating (Barendregt et al., 2008) for each activity and interpreting any trends in the data. The many open comments from pupils were analysed in a two-step emergent coding process involving first data reduction and then data visualisation to identify common themes, as described in Miles and Huberman (1994).

4.4 Findings

4.4.1 Device Focus
The video analysis suggests that the assignment of specific roles in each task and the introduction of auxiliary tools supporting these roles can help divert pupils’ focus away from the mobile device and towards their environment, team members and the current task at hand. Students were often seen standing or walking in a group to complete their role-specific tasks with only the device controller observing the mobile screen while students in supporting roles focused on their own auxiliary tools (Figure 6).

Figure 6: Roles and tools - left to right: Stopwatch, Metal detector (with integrated smartphone), Notes and Hooter

For the note-taking role in particular, which required prolonged interaction to make drawings of found objects, it was observed several times that the note-taker let the team move on while finishing a drawing before catching up, suggesting that the role and auxiliary tool fostered independence while working towards a common goal.
With respect to conceptualising smartphones as tools and integrating them into mock-ups of authentic archaeological equipment, it was observed that while the children tried to get a look at the device screen in key situations, e.g. when a virtual object was found, they usually focused on their own task and only helped to carry and operate the mock-up tool as required in Tasks 2 and 3 (Figure 7). Interestingly, students were clearly aware of the embedded smartphone but willingly accepted the mock-ups as functional tools, which was illustrated by the fact that they called them by their tool name ("Metal detector", "GeoFizz", "Digger") in normal operation but used phrases like "The mobile phone is broken" when there was a problem with the application.

Without any collaborative features or control functionality integrated into the mobile applications, the video material shows much face-to-face collaboration where students communicate with team members to coordinate their actions, discuss the line of action (e.g. in which direction to move while scanning the ground for virtual objects or structures), talk about found objects and their meaning or just express their excitement and enthusiasm. Students were also observed to engage with their physical environment, for example pointing out terrain features like small hills or dips and speculating whether these would be promising areas to scan with their equipment. In addition, there was regular communication with the teacher and archaeologist, who helped to structure and control the activities by prompting tool swaps between students and telling them when to finish and return their tools.

In the last outdoor activity (Task 3: Dig), where no virtual objects or structures were to be found, as students virtually "dug" at previously marked locations, and where consequently the teams had no regular and formalised consultations with the archaeologist or one of the present teachers or tech personnel, students were often observed to adopt a more playful attitude and to handle the equipment with less care. For instance, both cases where the mock-up tool disintegrated during use were observed in the third task involving teams on their own while the adults were busy with other teams.

Overall, the video analysis clearly shows that the involvement of the archaeologist, teachers and tech personnel into the activities motivated students, helped to scaffold their learning and encouraged them to stay focused on the task. In addition, it ensured prompt support when equipment broke or malfunctioned, deflecting attention from technical problems and helping students to engage with subject-related problems.

4.4.2 Device Sharing

Despite the mitigating effects of roles and auxiliary tools on device focus, children were still observed in some cases to gather around the mobile device like "bees around the hive" (Morrison et al., 2009; Eliasson et al., 2010), especially when no immediate action was required from students in supporting roles and the task at hand depended heavily on visual feedback on the mobile screen.

The involvement of the archaeologist, teachers and technical personnel into the learning activity seemed to be a critical aspect of the project. It was observed that alerting one of the involved adults, preferably the archaeologist, on each find and receiving affirmation and expert advice as to the found object's relevance and meaning seemed very important to pupils. Some pupils went to great lengths to attract the attention of the archaeologist when something was found, by calling and using the provided hooter for a long time, before either succeeding or eventually moving on without a consultation.

While in these situations some team members continued to respect the main tool controller's right to interact with the device and only pointed their fingers at the screen (Figure 8), students used a range of strategies to gain or defend control of the device, including grabbing the tool, pushing one's own hand towards the device (Figure 9), blocking the hands of others and pushing others' hands away from the tool (Figure 10). Children were also observed to exercise control by proxy, e.g. by resting a hand, often for extended
periods, on the arm of the device controller (Figure 11), by tugging and/or pushing the controlling pupil or by putting one or more hands on other parts of the mock-up tool further away from where the mobile device was encased.

4.4.3 Tool and Device Usability

Some children were observed to indicate through gestures and verbal references that the mock-up tools were heavy to carry over longer periods, which was also mentioned twice in questionnaire comments. However, these were isolated instances and overall the children seemed to have no serious problems handling the tools.

In terms of tool robustness, it was observed several times that the tool handle was not stiff enough and started bending under the weight of the rest of the tool (Metal Detector), that parts of the tool came off (Metal detector, Digger) and in two cases that the whole tool disintegrated (Digger) during use. However, these problems did not seem to suspend children's willing belief in the functionality and purpose of the tool, nor did they affect their resolve to complete the task at hand. Furthermore, in almost all instances these problems were promptly and easily fixed by the numerous helpers in attendance, without jeopardizing task completion or resulting in reprimands over pupils' sometimes rough handling of the equipment.

With respect to screen glare, the dark box in which the mobile devices were embedded to minimise glare problems did not fulfil its purpose. Children were often observed having difficulties reading the screen and trying to shield the device with cupped hands. The first-person video material confirms this problem, as the device screen is often difficult to recognise due to reflections.

5. CONCLUSIONS

Responding to recent research pointing out device focus as a “massive problem” (Göth et al., 2006) in mobile learning that is “seldom questioned or understood as a main research problem” (Eliasson et al, 2010), this paper has described how device focus and related issues like device sharing in collaborative mobile learning situations have been addressed in the Invisible Buildings project. Drawing on a set of recommendations formulated in Eliasson et al. (2010), which approach the problem of device focus on a conceptual and pedagogical level, the learning experience implemented measures that aimed to support face-to-face collaboration between students and divert focus away from the mobile device towards the learners' physical and social context.

These measures included:

- assigning students specific roles in outdoor activities and accentuating each role's importance and purpose in collaborative tasks with auxiliary tools
- using smartphones as a set of tools for completing tasks instead of instruments for structuring and controlling tasks
- embedding smartphones into large mock-up tools derived from authentic archaeological practice to

Figure 9: Team member pushing hand towards the device

Figure 10: Device controller removing team member's hand

Figure 11: Control by proxy - team member resting hand on device controller's arm for extended period

In some cases a communal control phenomenon was observed where four children locked shoulders or otherwise held each other tightly, and, looking down towards the embedded smartphone and/or the ground, moved as a single unit in small tentative steps, without it being obvious how decisions on direction and or speed were formed.
emphasise their task-specific purpose and heighten the game experience for students

- promoting face-to-face collaboration through a requirement for team interaction and teacher-led group discussions instead of embedding collaborative features into the mobile applications and finally
- integrating teachers and tech personnel into the learning activities to scaffold learning and keep students focused on the task.

The empirical evaluation of the project with two classes of primary school children suggests that these measures helped to mitigate device focus. While the study was not comparative and only evaluated the condition described here, it established that device focus was not a big problem in the project and that overall students showed a good degree of context awareness and independence while working towards a common goal. They understood and fulfilled their roles in collaborative activities, made use of the mock-up tools and auxiliary tools to complete tasks, communicated with team members in both task-related and social modes and engaged with the archaeologist, teachers and tech personnel to discuss the meaning of found objects and their wider implications in the context of the project.

In addition to evaluating the mobile learning experience with respect to device focus, the paper also took a closer look at the related problem of device sharing in collaborative mobile learning situations. While the measures mitigating device focus also reduced the need for device sharing, a range of behaviours and strategies employed by pupils to gain or defend device control were observed in key situations where all team members pushed towards the mobile device. Although these were less complex than children’s conflicts and competition over shared resources around a tabletop (Marshall et al., 2009), there seem to be interesting similarities that transcend technological context and point towards non-technical approaches in the learning experience design.

While the large number of adults involved in delivering, supervising and monitoring the learning experience was a design decision consistent with Eliasson et al's (2010) recommendations and proved to be very effective in keeping students focused on the task at hand, it also is a weakness in the overall evaluation of the learning experience: such a high adult-pupil ratio can potentially impact on validity due to the Hawthorn Effect (Tornock and Gibson, 2001) or "good bunny effect" (Robson, 2002), where the knowledge of being part of a research study and the presence of persons of authority can have a significant impact on the behaviour of participants. This is however an integral problem of most field experiments involving novel technologies with unreliable equipment, as they require the presence of developers for ad-hoc technical support and of researchers to collect data.

In summary, the experiences in the Invisible Buildings project seem to support the design recommendations in Eliasson et al. (2010) with respect to device focus in mobile learning and suggest they are equally applicable to the related problem of device sharing. Embedding smartphones into mock-up tools to heighten the experience and to emphasise their role as tools, and introducing auxiliary tools that accentuate and support students’ roles in collaborative tasks, extended these recommendations conceptually and physically. These measures were well received by students who willingly accepted the mock-ups as functional tools and made use of auxiliary tools in supporting roles.

While the large number of adults involved in the learning experience can be seen as a methodological weakness, it was an integral part of the approach evaluated in this study and in a wider context must be recognised as a common problem in the empirical evaluation of novel technologies.

6. ACKNOWLEDGEMENTS

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