ABSTRACT
Mobile technologies offer new opportunities for children’s educational activities in that they can be used across different locations and times. However the physical size of these technologies present interesting challenges when designing for collaborative activities.

When designing technologies the importance of collaborative tasks have often been overlooked. The replacement of low-tech artefacts with digital devices, for supporting multiple users, can inhibit the shareability of information.

We present three projects where mobile technologies have been used as part of a larger mixed reality experience. Novel technologies were used to support children’s collaborative activities in storytelling, an adventure game and during an outdoor field trip. Interaction with mobile devices within each project is reviewed and the authors highlight important considerations for their design and use across multiple contexts.

Keywords
Collaboration, mixed reality, mobile devices, learning, interaction

INTRODUCTION
In many everyday domestic, workplace and leisure settings people use their own mobility and the mobility of artefacts to coordinate their collaboration with one another [9, 10, 25]. So far, however, many of the technologies which have been designed specifically to support existing collaborative activities have in fact altered the nature of this interaction, for example, by constraining users to completing tasks at their desk (where their PC is based).

New technological developments in mobile, embedded and pervasive devices provide designers with an opportunity to better support existing forms of collaborative work, by providing the user with additional computing capabilities, yet delivering this through a ubiquitous channel.

Whereas a standard PC would physically limit the task to a fixed physical location, novel technologies allow users to be mobile and to simultaneously access information from the digital and the real world.

Introducing novel technologies into a collaborative context of use without designing to specifically support these activities, however, can inhibit co-present access to digital information. By simply providing the user with a mobile or embedded computer-based version of an existing artefact, the way in which users access and share information may be drastically altered. The nature of creating and displaying information using a digital tool will change the process of interaction with people and the environment.

Mobile devices have the potential to integrate with other learning activities and materials in the environment. Devices can connect abstract information with physical spatial information. This can enable activities to be situated in a relevant physical space, where the space that one is engaged in includes the device but is not limited to the screen.

Moving from the traditional desktop computer to mobile, palm sized computers presents new opportunities for learning. Mobile devices have the potential to augment physical activity spaces and enable frequent, integral computer use rather than the occasional and supplementary use of desktop computers. As Roschelle and Pea [17] suggest, this shift may be especially appropriate in cases where there is a high student to computer ratio, and children and teachers must relocate to a particular computer lab in order to make use of the technology.

Making the learning process an interactive and collaborative experience is beneficial from a pedagogical perspective. Group work with young children is well established in British schools [6] and research in psychology and education has demonstrated clear benefits of collaborative learning activities in a variety of domains for young children [16, 26, 28]. However, collaboration and learning will only occur if the technology is designed to fit within the context of use for which it is intended. With an inappropriate design, a mobile interface may equally prove to be a barrier to learning.

The work reported in this paper involves children aged 7-11 years. Whilst some individual activities occur during classroom learning, at this age education is a fundamentally social activity. In UK primary schools (ages 5-11), one class session may involve several reconfigurations of individual, small-group and whole class teaching. Group work requires relevant skills such as planning, negotiation, tolerance and the ability to listen to others [see 27].

While mobile devices are being designed and evaluated as personal and lifelong learning devices [19], we focus...
on mobile devices as collaborative tools. Education-based computer systems are traditionally designed as ‘single-user’ systems. Work has been carried out to extend the desktop for use by multiple users [1] and analyses have examined its influence on collaborative styles of behaviour [24]. Use of mobile technologies are of growing interest for children’s play and learning [11], however, there is still relatively little understanding of the ways in which mobile technologies might be designed to best support co-present collaboration.

Nonetheless, as Danesh et al [4] suggest, the mobility of these devices opens up the potential for children’s group collaboration. Rather than being limited to working with an allocated partner at a desktop computer, children can move around, interacting with many other children and in differing environments. Inkpen et al [7] examined the importance of mobility using questionnaires to examine children’s preferences for where they would like to be able to interact with computers, and found that the second most popular response was outside (with the first being in their bedroom).

For the above reasons, we have become interested in designing collaborative mobile learning experiences. Unfortunately, a key restricting aspect of current handheld devices on collaborative activity is the limited size of the screen.

“It may be that the maintenance of shared attention will be more problematic with smaller screens” [17].

Others have tried to solve the problem of small displays in mobile technologies in various ways, for example the augurscope was a device consisting of a wheel mounted screen combined with position sensors, which better affords collaborative viewing due to its physical size and design [18].

However, small screen size does not have to be, and indeed is not, a barrier to collaborative work. As shown in the examples described in this paper, there are ways we can design so that children can collaborate around a small device by paying attention to the detail of the interaction taking place. Small changes in the design and use of the device can enable pairs to share information.

While within this paper the authors focus on the design and use of mobile technologies the projects considered integrated mobile computing within larger mixed reality experiences, where tangible, mobile and ubiquitous computing are combined. We draw on our evaluations of mobile devices from three key projects on children’s playing and learning, and make recommendations for designers of how best to support these types of interactivity.

**NOVEL TECHNOLOGIES FOR PLAYING AND LEARNING**

Within the Equator project we have reviewed three collaborative learning and playing experiences from the KidStory, Hunting of the Snark and Ambient Wood projects. All of these projects designed and implemented novel forms of technology under tangible, mobile and ubiquitous computing themes. Each project aimed to support some form of co-present collaboration through technology use, although individual project objectives varied widely. In this section we describe the main aims and objectives of each project, and the reasons why collaboration was important for each.

**Collaborative storytelling in KidStory**

The KidStory project used tangible technologies to support groups of children in the creation and re-telling of stories [2, 20, 21, 22]. Technology design and evaluation was firmly grounded within a real UK primary school with children aged 6-7 years. Children created and re-told stories using a software package called KidPad [2, 5], which enabled children to draw and use scaling and link-based zooming to navigate around their stories. By scaling-up interaction with this software to a room-sized experience, the project also explored the potential of novel forms of technologies to support pairs, small groups and entire classes.

Tangible technologies, which were both graspable and touchable, were combined with physical or movement-based interaction sensors. The technology, once set-up, was fixed to a specific location, although the equipment could be taken away and installed for each session of use. The children could freely move around the ‘interactive space’ but not outside of it.

Mobile PDAs (Palm Pilots) were used to create sections of the story, which could then be uploaded and integrated into the overall story.

An iterative user-centred design approach was taken to designing, testing and refining prototypes throughout the three-year span of the project. This paper will however concentrate on one of the final experiences of technology use, where much of the analysis took place within Equator.

**Collaborative exploration in the Hunting of the Snark**

The Hunting of the Snark [13, 14, 15, 23] was a technology-augmented children’s adventure game. Children aged 7 to 8 explored in pairs to make the activity more playful and to foster joint reflection on their activities. At different stages of the game they entered different ‘technology installations’ where they could find out about a mysterious ‘Snark’ creature.

This experience was based within an aesthetically augmented laboratory, and each of the installations that made up the game was fixed; the children moved from one station to the next.

One of the first activities was “snooping”, where a mobile PDA (iPAQ) was used to track particular objects in a treasure hunt style of game. Virtual representations of real objects appeared when the user was physically close to the object.

A one-day experience enabled 4 pairs to take part in The Hunting of the Snark. Our observations are based on video-recordings of this event.
Collaborative discovery in the Ambient Wood

The Ambient Wood project uses mobile and ubiquitous technologies to augment children’s discovery of real woodland. One of the objectives of this project is to design technologies that do not take away from the users enchantment and immersion within the natural environment, but help them to explore and interpret what they discover through ‘bringing the far to the near’ and ‘making the invisible visible’.

At this stage of the project a full prototype ‘experience’ has been run and analyses are being used to modify and inform technology design for the final experience, to be held in late September 2002.

The experience enabled pairs of 10 to 11-year-old children to explore different habitats within a wood. Mobile technologies were used for taking measurements of light and moisture at different locations within the habitat. The outcomes from each measurement were displayed on a PDA in pictorial format.

Mobile devices were also used to receive location-specific information. As the users explored the woodland habitat, their positions were tracked. When they reached specific locations, visual and audio information was sent to them via speakers in the habitat and on their PDA.

Although of the Ambient Wood experience required children to collaborate between pairs, for our analysis we will focus on the co-present activities of two sets of pairs, when working out in the wood during a ‘dry run’.

ANALYSIS OF TECHNOLOGY USE

Each of the experiences described above were video-recorded and analysed by the authors. Our approach was to view the videotapes repeatedly with our main focus being how the groups or pairs of children used and collaborated around the mobile technology they were provided with. We were interested in how similar types of technologies implemented in subtly different ways for distinct purposes, affected collaborative behaviour. We stress the importance of viewing the videotapes with multiple viewers to provide multidisciplinary objectives over behaviour interpretation and to decrease the tendencies of seeing what one is conditioned to or wants to see [8].

Identifying how these novel forms of technology may support co-present collaborative activities, we aim to provide guidance to inform future iterations of technologies both within projects, and on a more general level. With each individual project we have either used (or plan to use) our evaluations to guide the design of individual technologies. However, when reflecting upon the set of projects as a whole, many of the issues identified with respect to particular types of activity are common across all three domains.

Mobile devices

Similar styles of technologies were used within all three projects to facilitate mobile interaction, but were used for different purposes and required various modes of interaction.

In KidStory, children created the content for their mobile digital drawing pad (based on a PDA) using a pen, and could then send this to be uploaded into their story, which was then projected on a large screen. In the Snark experience a modified PDA was used to ‘Snoop’ or hunt for physical objects that were hidden throughout the real world environment, and these were displayed as virtual representations. The dynamic display enabled a treasure hunt style game to take place. In Ambient Wood the children used two mobile devices in combination. One device measured moisture and light, and the other displayed the readings obtained. Additionally, the same display device triggered visual information dependent upon the user’s location within the habitat. Location-specific information was sent to the display when the user found themselves in particular locales.

Although all of the physical devices used had similarities at a surface level (all were modified PDAs), small differences in their design and use resulted in distinctive patterns of collaborative behaviour.

The mobile devices supported two main paradigms of use. Interactions were either performed between the user/users and the device, or interactions were location-dependent and reactive to their position within the real world (determined by where the user holding the device moved to). The following lists present examples of each paradigm.

Interaction between user and device:
- Drawing pictures in KidStory.
- Observing the continuous location-based signal in Snark.
- Triggering measurements and changing measurement mode (light or moisture) in Ambient Wood.
- Observing discrete location-related signals in Ambient Wood.

Location dependent interaction:
- Signals received dependent upon user location with respect to physical objects in real world - Snark.
- Measurement reading dependent on real world conditions of each location in Ambient Wood.
- Specific locales within habitat triggered additional, location-related, information in Ambient Wood.

These different forms of interaction are key, as they fundamentally influenced how ‘shareable’ mobile technology use could be, as described in the following sections.

Drawing in KidStory

Within the KidStory project digital drawing pads facilitated interaction, but were not reactive to the user’s whereabouts. The devices were designed to be
used primarily by an individual but they were also able to share their contribution to the story by uploading them to the large screen and therefore making them available to the whole group. While the physical size of the mobile devices allowed children to draw sections of their story individually, they could easily move around with the device. This enabled them to share information about their drawings with others. They often moved to sit next to other group members and as they worked on their drawings they discussed different elements of their pictures. In order to share their contribution with the whole group they uploaded it to the large screen display. Each child was therefore able to contribute to the creation of the joint story. The use of PDAs for input enabled children to switch smoothly between individual, paired and whole group activity.

![Figure 1 Children share their drawings on the handhelds](image)

“The integration of relatively cheap, simple wireless devices together with physical artefacts and spaces (including displays) creates interesting opportunities for seamlessly distributing learning activities between digital and physical worlds” (see O’Malley and Stanton, 2002).

**Snooping in Snark**

Whilst searching for objects the Snooper displayed cross hairs and ‘targets’ which needed to be lined up into the centre of the display. The user held the display in their hand and moved about the space searching for objects. The display continually changed with the child’s movement and meant that they had to constantly monitor the display in order to locate the object.

![Figure 2 Child with Snooper concentrates on the image on screen, while their partner also tries to look](image)

The Snooper alerted users to the presence of physical objects via a visual or audio cue. Thus the snooper acted as both an input device (for searching) and an output device (displaying results). Digital visual representations of the real physical objects were shown when the user was in a specific location, except on one occasion when sound was used to represent a physical object in the shape of a musical note.

Requiring the user to constantly monitor a detailed visual image that was responsive to their location made information sharing a difficult task. This was compounded by a requirement of the system for the snooper to be held so that the display was always parallel with the ground. The level of visual concentration required by the child holding the Snooper, combined with the devices’ sensitivities made it difficult for two children to use the device simultaneously. We observed that the different pairs adopted different patterns of working.

Some of the pairs took turns, although the child in control of the snooper always took charge of the activity. In order for the children to share information on the display the child with the device had to stand still. As the main process of searching for clues depended upon the child moving around the space this was not easily done and so the process of searching for clues was a predominantly individual one. This meant that their partner took a less active role in snooping, either by following the child with the snooper (but having little idea of the visual feedback transmitted to the device) or joining in with the real world object search and collection once the virtual object had been detected. The facilitator frequently attempted to encourage a more collaborative approach to working through instructing the child with the snooper to stand still so their partner could see the display, and telling them to wander around together so that both could see when objects appeared.
Measuring in Ambient Wood

During the Ambient Wood experience the child with the probe and mobile display was able to take measurements of moisture and light around the habitat while their partner used a walkie-talkie (WT) to try and gather information from a remote site. The child with the WT was clearly aware of their partner’s location within the space, and from their physical actions it was obvious that the child with the measuring device was taking readings when s/he was crouched on the floor, sticking the probe into the ground.

Figure 4 The physical position of the child taking measurements indicates to their partner the activity that is taking place

As the children were not often physically very close to one another, the mobile display was usually only within one child’s view. However, information was displayed on the PDA only at discrete moments. Once a reading had been taken, the same image would stay on the display until the next reading was taken or another message was displayed. Although measurements were taken regularly, the partner with the WT was able to come up to the ‘measurer’ and enquire about the readings periodically, or if they spotted that their partner was in a new area where the readings might be of particular interest. The mobile display was then often shared between the both children, and could be passed around or angled towards them so that they could see.

Figure 5 Images displayed can be shared as they are only triggered in certain locations

In addition to this, information was displayed on the mobile display device when the user entered one of three specific areas of the habitat. Again, the visual information was transmitted as a discrete event and would stay displayed until another locale was visited or a measurement was taken. This visual information was accompanied by sounds that originated from speakers placed within the wood. It was clear that the audio information was inherently much more ‘shareable’ than the visual information provided. It was equally available to both children, and their facilitator, and provoked discussion as to the meaning of the sound.

One of the aims when designing the Ambient Wood experience was that the technologies should augment the users experience of the real wood and should not engross the user in technology. By delivering occasional information (rather than a continuous flow of information) through the mobile display this was enabled. The children were not ‘searching’ the space for information, but this was delivered to them at specific points. As this was a surprising event the child receiving the message would call their partner over to see the display. As the message was a simple picture the display could be read with a quick glance.

DISCUSSION

We have described the collaborative behaviours from three projects where similar mobile devices, used in subtly different ways, have promoted different types of collaborative behaviours.

In both the KidStory and Ambient Wood experiences the children without the mobile device had their own tasks to conduct and role to play in the activity. This contrasts with the snooping activity where both children were attempting to uncover physical objects using a digital guide. Small mobile devices do not easily afford multiple users viewing their physical objects and they seem to best support more co-operative styles of working when partners have their own activities to complete, but come together on occasions to share digital information.
As it was difficult to share information, and it can really only be achieved periodically, the design of information to be shared using these kinds of devices is extremely important. Within the Snark experience the displays represented very visually complex and continuously changing pictures that did not easily afford sharing. In KidStory individuals controlled the information on the display, choosing when to share it with others. In Ambient Wood, the display consisted of still, stable and simplistic pictures. As the display was only changed or updated occasionally throughout the experience the children were able to share this information with their partner.

This practice of occasional sharing of mobile information could be enhanced by the more effective use of sound, as a way of indicating to both parties that some information is available of interest to them both. Within the Ambient Wood experience we observed that audio information was equally available to all participants and could be used to co-ordinate activities distributed throughout a space.

When the interaction between user and mobile device was reactive to the user’s position in space then this aspect of the interaction seemed to be clearly understood by the partner without the device. In KidStory when a child was uploading an image from their mobile device to a large screen display there was visual and auditory feedback. The visibility of the child’s action when moving towards the large screen display encouraged the other children to attend to the picture [22].

This worked especially well within Ambient Wood as both partners had their own tasks to complete. It was clear what the partner with the mobile device was doing from location and body position and so they could catch up with each other if they were interested in specific outcomes/readings from a particular area.

CONCLUSIONS
Outside of our consideration of the particular projects discussed, we draw three key general conclusions related to supporting co-present collaboration with mobile devices from our work thus far.

Firstly, our analysis of collaboration highlights the importance of occasional well-structured information rather than a continuous flow of information. It is often assumed that having the potential for continuously available information means that information should be continuously available. With a smaller, more punctuated delivery of information, children were able to attend to the environment or the collaborative task at hand, without having to monitor the screen continually. It is therefore much simpler for them to interweave the digital information into their on-going collaboration. Appropriate feedback such as a sound prompt or feedback can be used to convey the delivery of important information when attention to the content is needed.

Secondly, within KidStory we began to explore the use of beaming as a collaborative activity with handhelds. Devices can communicate directly by infrared beaming. This enabled children to beam their drawing to a specific person via a physical gesture. Children developed part of an image and then passed it on to someone else in the group to add more detail and so on. In parallel with the implication that delivery of information should not necessarily be continuous, we would like to suggest that collaboration with mobiles does not have to be closely coupled. Indeed, interweaving closely and loosely coupled collaboration may well prove a future avenue for mobile experiences. This form of collaborative activity has not been explored so far in the other two projects but may be another potential avenue for encouraging collaboration.

Finally, the design of the mobile device may enable collaborators to be aware of the state of the information through visibility of action (e.g. placing your moisture probe in the ground indicates a reading). Thus, whilst previous research has discussed the physical affordances of mobile devices for particular activities [e.g. 3], we would like to suggest that the importance of design lies as much in how co-participants see the device being used as how a participant sees it may be used.

Designing with users is very important to these procedures. The design of mobile devices is very task dependent and further iterative design with prototypes would help to investigate interaction around these devices. We therefore continue to work towards a situation where children and teachers will be able to choose appropriate assemblies of devices to aid learning.

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