Learning through digitally-augmented physical experiences: Reflections on the Ambient Wood project

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"Fast and bulbous" - In memory of Mike Scaife who was the inspiration and the instigator of the project

Abstract
Information Technology (IT) has become an ubiquitous part of education, with a wide range of software being developed and used nowadays to support children in their learning. A dominant model has been to provide information and learning material, that is accessed via the web through the use of desktop computers, in the classroom, the library or home. While the use of technology in this way is generally considered to be successful, it is limited in the kinds of learning activities that it supports. How else might we combine *technology* and *information* to *extend* learning? We report here on a very different approach, where we used a diversity of pervasive, hi-tech and mobile technologies to design a set of integrated, novel learning experiences, to take place outdoors in a wood. Our aim was to augment the physical environment with various forms of ambient digital information, such that children's interactions and perceptions of it were extended in surprising and unusual ways. In so doing, our goal was to get children to take part and learn more about scientific enquiry, through discovering, reflecting and experimenting in an ambient wood.

1. Introduction
Ambient Wood is a multi-site project, within the learning and playing theme, that builds upon the experiences and lessons gained from the Hunting of the Snark project (Rogers et al, 2002). A playful learning experience was developed where children explored and reflected upon a physical environment that had been augmented with a medley of digital abstractions. The latter were represented in a number of *ambient* ways, designed to provoke children to stop, wonder and learn when moving through and interacting with aspects of the physical environment. A variety of devices and multi-modal displays were used to trigger and present the 'added' digital information, sometimes caused by the children's automatic exploratory movements, and at other times determined by their intentional actions. To this end, a field trip with 'a difference' was created, where children had to discover, hypothesize about and experiment with biological processes taking place within a physical environment.

The physical world that formed the basis of the experience was a real wood (see figure 1), inhabited by a rich assortment of living and dead forms. The children explored, observed and probed these by looking, listening and touching what was around them. To assist them, they were given various computer-based devices, that allowed them to do and see things they could not do otherwise. These included making the invisible visible, making the inaudible audible, bringing the far to the near and seeing the past and the future in the present, through using an assortment of digital media, in the form of visualisations, videos and sonifications, that were coupled with the physical entities they were referring to. The rationale for combining the physical and digital in these ways, was to give children the means by which to integrate their perceptions of the real wood (e.g. seeing a butterfly sitting on a thistle) with their existing knowledge and received information about the physical processes taking place in the habitat (e.g. "the meadow brown butterfly likes the warmth and lays its eggs in the grasses from May to September"). A central claim of our research is that such couplings – that were intentionally designed to be novel – would make more explicit the nature of the distributions and relationships of the organisms in the habitat, and in so doing facilitate the learners' ability to better integrate their disparate experiences and knowledge (Scaife and Rogers 2001).

Figure 1. The woodland

From a theoretical perspective, we wanted to enable the children to learn how to integrate their understanding and knowledge through a dialectic process of reflecting and acting (Schon 1991), and to do so in a playful way (Bruner et al 1976; Bruner 1979). This required us to design fun and engaging ways of perceiving and experiencing the world. We also wanted the children to make sense of, and understand, the processes underlying the physical world holistically, by thinking beyond and across formally demarcated disciplines (i.e., science, nature and technology). This is something teachers find difficult to achieve, given the current constraints of curriculum-bound classroom learning.

1.1 The benefits of incorporating physicality and tangibility into learning

Recently, there has been much interest in bringing 'physicality' into computer-based learning. By this is meant active physical manipulations in various forms, such as, manipulation with real world objects, gestures, and bodily posture changes. An approach that exemplifies this, is tangible-mediated learning, where the digital world of information is coupled with novel arrangements of electronically embedded physical objects, providing quite different forms of learner-interaction and system behaviour than that provided by the default set-up of keyboard, monitor and mouse. A claim often made about these alternative forms of interaction is that they capitalize on people's familiarity with their way of interacting in the physical world (Ishii and Ullmar 1997), and in so doing, provide different opportunities for reasoning about the world through discovery and participation (e.g. Soloway, Guzdial and Hay 1994; Tapscott 1998), thus providing benefits for learning. However, while this may be true in certain contexts, we argue that it is not familiarity *per se* with the manipulation of physical artefacts that provides the benefit for learning (since nowadays many children are as au fait with using technologies like remote controls and computers as they are with physical building blocks) but it is what the familiar actions are coupled with. In particular, a further claim of ours, is that it is the juxtapositioning of familiar actions with *unfamiliar* effects that is key, provoking reflection, and in so doing, providing new opportunities for designing learner experiences that allow children to see relationships and processes within systems, etc., in new ways and from different perspectives. In turn, this can provide alternative ways of helping them integrate their knowledge.

Various learning environments have been developed that have tried to show the benefits of having physicality and tangibility designed as part of a computer-based learning experience (Colella et al 1998, Resnick et al 1998, Cassell and Ryokai 2001, Stanton et al, in press). Our preliminary contribution to this research, has been to examine the added value of providing novel forms of physical embodiment, through the use of various forms of physical/digital transforms and traversals (Rogers and Scaife, 2001; Rogers et al, 2002). In our previous Equator project, called the Hunting of the Snark, a game was designed that required children to move around and interact with a number of novel physical/digital spaces, by using highly familiar physical actions (e.g. walking, flapping arms, manipulating physical objects). These were coupled with a range of unexpected outcomes (e.g. flapping of arms, as if flying, would cause a digital animation of an imaginary creature to appear above the children. Moreover, the frequency, pitch and coordination of the children's arm movements had an effect on the emotional state of the creature and changed its behaviour towards them). The project was highly successful in engaging the children, facilitating a sense of awe and wonderment at the digital effects caused by their familiar physical actions, as indicated by the sophisticated accounts that were pieced together by the children, of what was happening and what caused certain events to happen and why (Price et al, 2002).

This and other tangible-mediated learning research has focussed so far on designing around the kinds of physicality afforded by man-made artefacts (sic), like mats, clothing, bricks and cubes. Our current project, the Ambient Wood, seeks to extend this research, by exploring how the affordances and physicality of both man-made artefacts combined with the rich array of real things found outdoors, can be exploited and designed around, opening up new ways of supporting learning. Specifically, our goal was to provide a range of interconnected learning activities, aimed at engaging children with their immediate physical environment, but at various times surprising them with unexpected and novel digital events, that were caused through their actions. In so doing, it was hoped that the children would start to think beyond the here and now of their physical experiences to higher levels of abstraction.

2. Multidisciplinary collaboration

Moving outside into the physical world, away from our labs, created many challenges for us, not least having to cope with the lack of a readily available computer network and a continuous supply of electricity. Instead, we had to find a way of providing a local area network that could cover the large and unpredictable terrain of a physical wood. Obstacles had to be overcome, like the interference of leaves, tree trunks and weak satellite reception. In addition, all out devices, computers and monitors had to be powered by batteries, restricting the time we could have anything running for.

A key technical challenge was determining how to make the wood 'ambient', enabling digital representations to be pinged, accessed and sent around a range of mobile and stationary devices, including PDAs, wireless speakers and monitors. A robust infrastructure had to be built that could:

• track the physical movement and presence of the children as they walked around the wood
• record and save a variety of real-time readings collected through the use of devices of certain variables in the wood

In addition, much thought needed to go into the design of the digital representations and in what form they were to be presented, as well as which physical interactions and couplings to use with which kind of digital representations, for example, when to present a sound or a visualisation and in response to what.

Hence, a whole range of design decisions had to be made, covering a diversity of problems. This would have been impossible to accomplish by one set of researchers with a particular background. To this end, we assembled a multidisciplinary team, from five sites (Sussex, Bristol, Nottingham, Southampton and the RCA) having backgrounds in cognitive science, developmental psychology, educational technology, interaction design, computer science, software architecture and hardware engineering. The following set of core activities, spanning the different areas, were carried out by the various members of the sites, assembling together to meet the requirements:

• programming and integration of devices and technologies
• design, building and engineering of novel customized devices
• creation of a wireless network to work outdoors
• pedagogical and conceptual development
• content design for digital augmentation
• scenario creation for learning activities

Several workshops and discussions with biologists, teachers and other experts were held to identify what aspects of a field trip would be appropriate for digital augmentation. Many scenarios and domain spaces were explored as potential candidates of which most were rejected when it was realised that they were

either too difficult to accomplish, or they were not capitalizing enough on the physicality of being in the wood environment. Three key questions we asked ourselves when shaping the learning experience was:
• how exactly were we augmenting the physical?
• what was novel about the experience and what was the added value of doing so?
• were we proposing something significantly different from what children already do when on field trips and in the classroom?

3. Learning domain

It is well known that learning through doing and experiencing is central to understanding. Many learning activities have been designed with this in mind, field trips being a particularly popular form of getting children to learn through observing and doing. A perennial problem with this approach, however, is the difficulty children often experience when trying to relate their physical experiences gleaned from the 'doing' with the more formal science they need to learn that is associated with it. In particular, children have a difficult time trying to map their experience with the physical world that they can readily relate to (e.g. birds eating worms) and generalise from (e.g. animal Y eats organism X) with the higher level abstractions they are taught in the classroom that represent these as inter-related dynamic processes (e.g. food web diagrams representing energy flow in an ecosystem) – necessary for being able to make complex inferences about them.

Previous research has used a variety of desktop technologies, like multimedia and VR, to help students bridge the gap between concrete and abstract representations (e.g. Rogers and Scaife, 1998). Here, we decided to design a learning experience that would provide children with novel ways of integrating different kinds of knowledge and physical experiences. After much consultation with experts and teachers we decided upon the topic of habitats, which can be physically experienced while also needing to be understood at a number of levels of abstraction. The physical aspects of the habitat can be discovered by asking children to find out what specific organisms live in particular habitats and why some thrive better than others. To understand the habitat at a higher level, requires knowing more about the underlying processes that support it, which are typically described in terms of systems and cycles. Our goal, was to see whether we could enable children to move between the different levels of knowing and understanding, being able to both experience the conditions and to hypothesize about, for example, the processes which enable a particular habitat to thrive or not. And, importantly, to try to do this, by providing engaging and provocative digitally augmented physical experiences.

4. Designing the overall learning experience and integrating the learning activities

Our main focus for the learning experience was supporting the development and application of scientific enquiry skills for a given science topic (habitats), which fits in with what children are required to learn about as part of the school curriculum, but which can be difficult to accomplish because of the different components that have to be brought together and applied in the appropriate manner. Scientific enquiry, typically, involves a number of interdependent and iterative stages: namely, exploring, discovering, consolidating knowledge, reflecting, making hypothesizes and testing them through experimenting. Understanding how the various processes relate to each other, and how to use the results of one to feed into another, requires the integration of doing and knowing and, furthermore, to generalize across instances.

The age we targeted our learning experience at was 10-12 years. Children of this age are still young enough to find novel augmented experiences fun and engaging but also old enough to use them in the pedagogical manner intended. A series of activities were designed, based around the topic of habitats, focusing on the plants and animals that live in the different habitats of a woodland and the relationships between them. They were intended to enable children to learn about habitat distributions and interdependencies within them. Two contrasting habitats were selected for this purpose: an open clearing and a wooded area. These are quite distinct and have different distributions of organisms and interdependencies among them.

To facilitate the understanding and application of the different components of scientific enquiry, the learning experience was structured, being broken down into three distinct stages:

• Exploring and discovering
• Reporting back, consolidating and hypothesizing
• Experimenting and reflecting

The activities within these stages were designed to provide a range of opportunities for the children to move from their concrete physical experiences to abstract representations of the environment, and back again, in an explicit and progressive manner. The learning experience was also designed for pairs of young children to collaborate during their explorations. At this age, learning is very much a social activity, and so we wanted to draw on the benefits of collaborative discovery and exploration, where collecting of data and reflecting on these was done together. It was also intended that the pairs of children exploring the different habitats, would come together at various stages, so that they could share and compare with each other their experiences of the different habitats (see Stanton and Neale, 2002).

4.1 Stage 1 – Exploring and discovering

The first part of the learning experience was designed to enable different pairs of children to go out into the wood to explore two areas of the woodland (a clearing and wooded area). The goal was to enable the pairs of children to find out about things in the habitat - what grows there and why, and what lives there and why, e.g. birds nest in certain trees, animals visit certain locations because of the available food nearby, such as a particular plant life – and to discover these things both through the naked eye and ear as well as via the use of a variety of devices and other pervasive technologies.

The habitats were augmented with digital information and presented in a number of ways. These were sounds, animations, abstract visualizations, voice-overs, video clips and images, representing the relationships between organisms in the habitats. They included:
• growing processes (e.g. the sound of a thistle dying, an animation of bluebells growing and dying over time)
• feeding behaviours (e.g. the sound of a butterfly drinking nectar from a thistle)
• readings of processes (e.g. light and moisture visualizations)
• locomotion behaviour (e.g. a video of a creature moving around in leaf litter)
• dependencies (e.g. an animation of what would happen if a spider and fungus was introduced to the wooded area)
Hence, some of these were realistic representations of organisms that the children were unable to see and others were abstractions of processes that were not normally visible or audible.

The children were kitted out with various technologies that enabled them either to discover this information themselves (using PDAs connected to probing tools) or for it to be presented to them in a pervasive way, triggered by their physical presence in a part of the habitat (using pingers, PDA, GPS and tracking equipment).

(i) Probing devices and PDA combination designed to discover aspects about the wood and make the invisible visible

The combination of using a PDA and probing device enabled the children to take readings of two core parameters that affect the state of a habitat (see figure 2). These were light and moisture. The probes were designed to allow the children to take readings themselves, wherever they wanted to, by physically pushing the prongs of the device into any part of the habitat (e.g. ground, leaf, tree) to get moisture readings or by holding them up in the air in different parts of the habitat to obtain light readings.

The probing device was designed to be dual-purpose, easily being able to be switched between moisture and light reading mode. This allowed the children to get two sets of different readings and compare them across the different parts of the habitat.

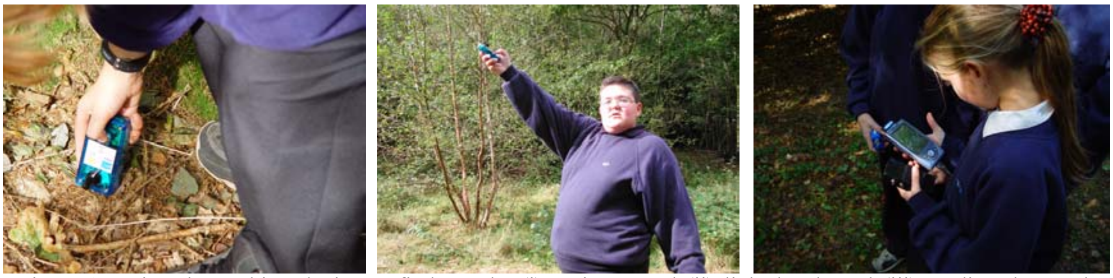

Figure 2. Using the probing device to find out the (i) moisture and (ii) light levels and (iii) reading the resultant visualisation on the PDA screen

The readings were re-represented as simple animated abstractions that were displayed on a PDA, showing the relative intensity of moisture or light (see figures 3 and 4). This allowed the children to rapidly discern how moist or light a part of a habitat was relative to the rest of it.

Figure 3. Moisture reading (medium level)

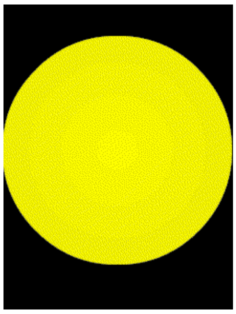

Figure 4. Light reading (high level)

(ii) The use of the PDA to present digital representations, drawing children's attention to certain processes

Occasional digital information was also presented to the children via the PDA, about a particular aspect of the habitat, depending where they were within that habitat. Various sounds, images and voice-overs were triggered to appear through the use of pinger technology (Randell and Muller 2001), depending on their location in the habitat. A sound would be triggered first, which was transmitted through wireless speakers hidden in the habitat. The sound was followed, five seconds later, by the presentation of an image and voiceover on the PDA. The purpose of providing this combination of distributed digital information was threefold: (i) introducing the unexpected – the sounds were intended to be fun and attract the children's attention to a specific part of the habitat, (ii) enhancing the perceptibility of aspects of the woodland, e.g. by visualising processes that would be difficult to see or hear otherwise and (iii) providing explicit information conveying the interdependencies between the organisms. Eight sounds in each of the two habitats could be discovered, for example, the butterfly sipping nectar, the chiffchaff eating a caterpillar and woodlouse scuffling. Associated with these were eight images and voice-overs that appeared on the PDA, for example, a thistle growing, the butterfly feeding, woodlouse having babies (see figure 5). An example of a voice over was: "woodlice and millipedes live in and feed on the fallen leaves".

Figure 5. Example digital images presented on the PDAs

(iii) The periscope, showing visualisations and video clips of how the habitat changes over seasons

A special periscope device (see figure 6) was built that enabled the children to view other processes occurring in the woodland habitat that would be impossible to see with the naked eye or ear. The aim was to provide abstracted information (visual and audio) of life cycles already present in the woodland. These were presented as quicktime movies and animations showing the changes over time; which organisms lived there and the interactions that took place between them.

Figure 6. The periscope

A Director movie was made which showed a panorama of the wood and contained a number of thumbnail images, which represented links to the movies. By navigating through the panorama and finding and choosing links, the children were able to view the lifecycles of woodlice; to see up close some of the tiny creatures who feed from the leaves and leaf-litter; to see the way the wood changes its character over a season, or a period of fifty years (see Figure 7). They were also able to see time-delay footage of various stages of the bluebells' lifecycle, and some of the interdependencies, which are an inherent part of the woodland's character.

The design aesthetic of the periscope was centred around the idea of a high-tech organic hybrid. The 12 year olds with whom we did initial testing seemed most impressed, interested in and intrigued by visible technology, which seemed to be more advanced than that with which they were familiar. Initially conceived as more of a "portal" into the wood's hidden life, the periscope became less and less hidden or pervasive and more of a visually and physically present piece of unfamiliar technology in the woodland habitat. The intention though was to create some sort of organic form (out of mostly inorganic materials) that hopefully went a little beyond the children's assumptions about technology.

The periscope consisted of a 6.5" diagonal flat screen, which was mounted onto a tubular stainless steel "stem". The screen was protected from light by a custom-made black rubber "hood" which was designed to resemble some sort of flower or cluster of leaves. The form of the "hood" was maintained with curved aluminium wire, which, from certain angles, seemed to resemble antennae. Horizontal navigation within the Director movie was effected by turning the hooded screen on its axis, using bicycle handles, which protruded from the sides. To navigate vertically, the children could twist the bicycle handles in place, forwards or backwards (*up* or *down*). Laid over the navigable panorama, within the movie, was a representation of crosshairs – like an aiming site in an actual periscope. When the thumbnails passed underneath the centre of the crosshairs, they enlarged a moment in order to make their contents clearly visible before linking to the appropriate quicktime movie. Once the quicktime movie finished, the screen went straight back to where it was before the movie appeared – with an enlarged thumbnail of the movie, which had just been viewed and the possibility of navigating elsewhere and linking to other movies.

Figure 7. An example of a quicktime movie being shown on the periscope

While in the woodland the children could find physical organisms, such as woodlice, and go back to the periscope to find the icon associated with these and access more information about the lifecycle or habitation of it. They could also look at artificial examples of the organisms found in that part of the woodland, that were presented in hanging Petri-dishes, that were attached to the periscope.

To facilitate retention and integration of the information discovered, the children were required to relay their findings, via a walkie-talkie, back to an adult facilitator. The adult would also occasionally ask them questions about what they had found and the significance of this in relation to the overall habitat.

4.2 Stage 2 – Reflecting, consolidating and hypothesizing

Following the exploratory stage, the pairs of children were brought together and taken into a 'den' (a makeshift outdoor classroom-like setting), where a large computer monitor and shared interactive display were provided (see figure 8). The aim was to provide a collaborative neutral environment that would allow them to report back to each other and reflect and consolidate their findings. In particular, the goal was to enable the children to step back from the physical action and to think more explicitly and holistically about the collection of readings they had collected in relation to the two habitats and the processes and relationships between the organisms within the habitats.

Figure 8. Pairs of children sitting around screen displays used in Phase 2 of learning experience

The children sat together in a semi-circle in front of the two displays, with an adult facilitator standing beside them. To begin, the children were shown, on a large display, all of the light and moisture readings they had taken during their exploration of the habitats. These were represented as blue or yellow dots on a birds-eye representation of the two habitats (see figure 9). They were asked initially to predict what the reading would be for each dot (e.g. high or low moisture) and to explain to the other children why this was the case. They were then allowed to click on the dot in question, where upon the same visualization they had collected and seen in the habitat on the PDA screen, popped up as an iconic representation on the large display, along with a corresponding numerical reading. The children took it in turns to predict and explain to the others, enabling them to make comparisons between their own readings and across the different habitats.

Figure 9. Display showing aggregated probe readings for the two habitats

They were then asked to consolidate what they had learned about their habitat, by building a picture of it, using paper 'tokens' representing the organisms, which they stuck to the interactive board (see figure 10). These were tagged and when placed onto the board were read by a tag reader, which resulted in feedback being presented on the accompanying computer screen at given times. A number of tokens were provided, from which the children had to select the correct combination that they thought made up the habitat (e.g. chiffchaff + caterpillar + brambles) and to explain the nature of the relationship between them (e.g. the chiffchaff makes its nest in the brambles and eats caterpillars and other insects.). If they selected the incorrect combination, an animation appeared on the computer monitor, providing feedback to this effect (see figure 11). When they got the correct set of tokens and placed them in the correct locations, the system would provide positive feedback to this effect.

Figure 10. Token use on interactive whiteboard

Figure 11. Feedback provided from tagged tokens

Following this task, the children were asked to generalize to another setting, specifically to hypothesize about what would happen to the organisms and their interdependencies that they had identified as being part of their habitat during the winter (the season they had explored their habitat was late summer).

4.3 Stage 3 – Hypothesizing and experimenting

Following stage 2, the children were told that they were going back into the woodland to do some experimenting, and in particular to see what would happen if the two habitats were changed in some way. A hypothetical scenario was presented to them initially to think about what would happen if an acorn was planted in the middle of each of the habitats. This is something that they would be able to easily imagine in the context of what they had just experienced in the wood and already knew about habitats. A key question for them to consider was whether it would thrive in the two different habitats and what effect it would have on the other organisms.

Following a discussion of this scenario, the children were asked to think about what would happen if two different types of creepy organisms, that they did not expect and had not come across in the wood, were introduced into the wooded habitat. These included a large white hairy spider and a nasty form of bootlace fungus (see figures 12 and 13). These were artificial, but designed to look and feel as realistic as possible. The reason for selecting these two organisms and presenting them in this way, was to make the experimenting stage of the learning activity to be authentic, slightly scary and engaging, enabling the children to suspend their disbelief that they were artificial, for the purpose of the learning activity. Our previous research has shown that the genre and look and feel of artefacts that children are given to hold, wear or use is critical as to whether they are willing to go along with the make-belief of the exercise associated with them. This is especially so for the 10-14 year old range, where we found children of these ages to be embarrassed and resisted having to put on cyberjackets, rucksacks or other wearables, that were perceived by them to be too girly(or boy)-like, too baby-like, or too geeky. User studies of what organisms children found interesting and fun were those that were scary and creepy. Hence, our choice of fungus and spiders.

Figure 12. Placing the fictional spider next to periscope

Figure 13. Bootlace fungus in Petri-dish

The two pairs of children were led back into the wooded area towards the periscope, and were asked to continue their reasoning as they walked. As with the acorn scenario, they were asked to hypothesize what they thought would happen, and, in particular, whether it would have a detrimental effect. They were told that when they reached the wooded area with the periscope, they would be able to see on the screen what would happen over time when these two tokens (representing the two types, respectively) were placed separately and together in the wooded area.

To add a sense of suspense, the fictional spider was enclosed in a ring-pull can. The children did not know what exactly what was in the can and were required to open it once they were out in the woodland habitat by the periscope. The children were then able to verify if their hypotheses were appropriate. They did this by placing the RFID-tagged artefacts – the Petri-dish of fungi and the spider (now released from its can) - within range of the RFID tag reader aerial. Once a tagged item was placed within range, an animation would be viewable on the periscope's screen. The animation showed the outcome of introducing either one or the other or both the tags together into the woodland environment. These were:

1) White spider alone
The white spiders in the woodland eat lots of different creatures and bugs, as well as providing a source of food for the birds, attracting new species of birds to visit. The introduction of this creature does not have a detrimental effect on the habitat.

2) Bootlace fungus alone
Bootlace fungus grows on birch trees. The fungus kills off these, allowing the oak trees to continue to grow slowly and eventually take over the woodland. Blue bells continue to grow in the spring. The introduction of this organism has a detrimental effect on the habitat, with one organism dying and the balance of the habitat to change slightly.

3) White spider and Bootlace fungus combined
The spiders eats all the creatures that are attracted by the fungus, but not the fungus, and the fungus becomes even more rife than without the spiders. The fungus kills off all the birch trees, but the oak trees are not

> attacked and continue to grow. The introduction of the two organisms together has the most detrimental effect on the habitat, causing two organisms to die and the balance of the habitat to change dramatically.

Following this phase of experimenting, the children were then taken to the other habitat to see what would happen in the clearing habitat if it were to flood or become very arid. Again, they were asked to imagine and then hypothesize before doing any experimenting and to explain their reasoning. Upon reaching the clearing, they went about using the probe and PDA combination to get the new readings. This time, the digital moisture readings had been 'fixed' for the different locations, showing very wet or very dry readings, depending on whether they were on high or low ground (the light readings were unaffected). Different sounds were also triggered via the pingers, when the children walked passed them, indicating the effects of making the habitat very wet or dry. The children were required again to make predictions and give accounts for the different readings they observed.

5. The system architecture and integration of technologies

The hardware platform solution required to support the number of devices and systems needed for the learning experience had to cope with the constraints imposed by trying to network a physical wood. After much experimentation with different set-ups, we chose a flat IP network over a bridged 802.11b wireless link. This gave the most reliable and strongest coverage. This was enabled by laptop PCs acting as wireless LAN access points, operating under Linux. The devices, pocket PCs and other laptop PCs, had their own wireless LAN cards on board. Other devices communicated wirelessly, either with the use of Pingers (i.e. short-range radio) or RFID tagging technology. To enable this hardware model, a two tier software strategy was employed, using Elvin and the Lima/MUDOS MUD library.

5.1 The MUD architecture

Lima/MUDOS, a Multi-User Dungeon software architecture, offered an appropriate abstraction for modelling the structure and interactions between the different participants in the environment. Whilst typically deployed as a gaming environment for role-based adventure games, the MUD models shares much in common with real-world orchestration activities, such as those proposed for the learning experiences in the ambient wood.

The MUD maintained virtual representations of all of the physical artifacts in the wood (e.g. locations, devices, people, and probes). Through Elvin notifications, processes scripted within the MUD, orchestrated the scenario logic by triggering events in the physical world, such as the sonification of alerts, visualizations and voice-overs on the hand-held devices based on the new state of the model.

By adopting a MUD for orchestration, the scenario logic was abstracted away from the devices. This enabled rapid, virtual prototyping of scenarios, in that the wood events could be simulated within the MUD and all interactions explored without dependency on other infrastructure or participant devices. Also, by modeling all of the physical interactions within the MUD, should any device failure occur during the live trials, it was possible to simulate, or 'Wizard of Oz', the interactions in the virtual environment and the MUD would still enact the appropriate resultant events. Further information about the use of MUDs for orchestration can be found in (Thompson et al, 2002).

5.2 Elvin notification system

The Elvin notification service (Segal and Arnold, 1997) was employed to mediate communications amongst the various devices in the wood. To enable this, the following programming was undertaken:

- A small C program was written to drive the tag readers, to translate the tag IDs into symbolic names, and to emit Elvin notifications
- Another small C program was written to play sounds on the speakers hidden in the trees.
- The Director movies employed the Elvin Xtra to communicate with the notification service
- A Java proxy was written to translate between Elvin notifications and the MUD.
- The Elvin client library was ported to Windows CE and integrated into the probe software.

5.3 The devices and tracking system

In order for the environment to react to the children's activities, and for their monitoring devices to be activated at the right time, we needed to be able to sense their location. We used three positioning systems for this: GPS, pingers and dead reckoning. GPS, with high gain aerials, were used to identify global position. However, given that the children were moving around under trees, GPS was found not to be very accurate. The second system we used was pingers – local radio beacons, which are 'visible' in a range of 3-10 meters. Pingers can be used to identify when a person enters a zone, and based on this to trigger an appropriate digital event. The third system that we used was based on dead-reckoning. This system is experimental, and uses motion sensors to estimate where a person moves (Djiallis in prep).

Two probing devices were built to measure light and moisture levels. The probes were designed to have an alternating light sensor to measure whether an area of the woods is dark or light, and a moisture sensor to measure whether the ground is dry or wet. The probe was designed as a wireless device, meaning that a child could put it in the ground or in the air and obtain readings from different aspects of the habitat. Because of the complexity of the 802.11 network, however, the probe was designed with a single chip radio transmitter to transmit a reading asynchronously. The reading was picked up by a wearable device and passed on to Elvin using the 802.11 network. The radio devices used are the same one that pingers use to transmit their pings.

One of the children of each pair wore a backpack that was kitted out with the GPS. Each time they took a reading with the probing device, it was recorded over the Elvin/MUD system and sent back to a central computer. Each reading and its location were fed into a software programme, that collated all the readings and presented them as an information visualization, which the children could view and interact with in the den area. The children were unaware that this form of tracking and recording of their probing activities was taking place until they returned.

The periscope was built as a stand-alone device, with a metal-based stem of adjustable height (the height variance of 10 to 12 year-old children can be quite dramatic). A number of curved items protruded from the "stem" of the periscope about two thirds of the way up from the ground. One of these was a circular copper aerial, which was attached to an RFID tag reader, with the cable wound vine-like around and down the periscope's stem. The aerial was attached to the periscope's stem with curved tubular (non-conductive) plexiglass. The resistors and capacitors which formed part of the associated circuitry, and which protruded from the exterior of the aerial, were enclosed in a small transparent petri-dish. This protected the children from incidentally (or intentionally) touching the heat-conducting elements of the circuitry, while at the same time, maintained a kind of transparency of technology, which can be seen elsewhere, in the probes, for example. The aerial was then crisscrossed with a network of invisible nylon thread and had a petri-dish holder hovering just above the actual aerial within it's reading range, suspended in place with the use of another curved piece of plexiglass tubing.

Echoing the form of the aerial and its petri-dish holder, were a number of aluminium wires which curved off from the periscope's stem in various directions, and which ended in circles which were approximately the same size as the tag-reader aerial. "Trapped" in each of these circles with a network of "invisible" nylon thread were various petri dishes which contained elements which related to each of the quicktime movies in the periscope movie – bluebells, acorns, leaf-litter, critters, fungi, etc. These elements already existed in the wood and were trapped, and representations of them accessible, within the periscope. On the base of each of the petri dishes, and clearly visible, were RFID tags. The design was created in this way to allow the children to deduce for themselves what they would need to do with their RFIG tagged tangibles when it came to the experimentation stage.

5.4 The interactive board

An interactive board was developed, using two RF aerials, that enabled tagged items placed in two different sections of it, to be recognized. This was designed to allow the two pairs of children to work side by side. The board was placed vertically in front of the children instead of as a conventional horizontal table, as a previous pilot study had shown that there was more of a propensity for the children to place the tagged items indiscriminately onto a horizontal board without much thought. Requiring the children to place them on a vertical board had the effect of slowing them down, and in so doing, made them more judicious as to their selection of tagged items to depict. The surface of the display allowed the tagged items to be attached and removed, triggering certain digital events to appear on an adjoining computer monitor. These consisted of animations and voiceovers and were given in response to a pre-determined number or combination of tokens placed on the board.

5.5 Technology placement in physical environment

The running of Ambient Wood was heavily dependent on technology, which was deployed throughout, and as such the uninterrupted supply of power to the technology in the form of batteries became critical. Where necessary, battery packs were made that sought to provide a 50% power redundancy for the duration of the experience. Once the power was in place and the wireless network running, the location of the pingers and wireless speakers needed to be decided. Although we worked from a model previously built, we needed to fine tune the positioning of the actual pingers and speakers in relation to their receivers and transmitters, respectively. To position the pingers, the desired live area of activation was occupied by a pinger receiver, whilst the pinger transmitter position was moved until it matched the boundary requirements. To position the wireless speakers and their transmitters required as best line of sight from the transmitters as possible to minimise any hissing caused by the receivers getting a poor signal. This also meant positioning them so that the line of sight would not be broken by children getting in the way when exploring.

5.6 Recording and communication devices

While exploring the two habitats, the respective pairs of children were required to communicate with two adult facilitators, who were based in the den area, using walkie-talkies. These operated on the 446MHz frequency range, providing a range of up to two miles. The functionality for the devices was restricted to talking and listening only.

Radio mikes (Sennheiser evolution 100series) were used to collect audio data from the children throughout the learning experience. These operate on four preset frequencies between 863 and 865MHz and have light unobtrusive transmitter boxes with omni-directional "clip-on" microphones. They had a pickup range of between 20 to 30 meters in the wooded area and twice that in the clearing. As the two habitats were sufficient distance from each other, the same frequency could be used for both, with the placing of the RF receivers, accordingly. Two recording devices were used to save the data, a Sony memory stick ICD-MS515 recorder and a Sony Walkman minidisk.

6. Trialling the Ambient Wood

Two days were set aside to run the Ambient Wood learning experience (following a trial run held for 2 pairs of children a month earlier). Sixteen children aged 11 years took part. Two sessions were run each day with 2 pairs of children taking part in each session. Two sets of girls and two sets of boys were chosen and pairings selected by their teacher. As far as possible, each group of children were from the same class, in order that they knew each other, promoting interaction within the pairs. Children were taken out of school, accompanied by a teacher, for the morning or the afternoon, to take part in this experience, and were therefore participating from an educational perspective.

Each session took approximately two hours in total, including technology set up time for each session. Between each session the technology had to be switched off to maintain battery power, and restarted and re-checked before the next group of children could take part. Children were given instructions at various relevant stages of their experience and given the chance to try out the devices. Children were initially kitted out with various devices: wireless mikes, GPS tracking, walkie-talkies, the PDA and, later, the probe tool. To kit out each group of children with equipment, give explanations and trial time took about 15 minutes, followed by the exploration phase, which generally lasted about 30 minutes. The reflecting sessions in the den lasted about 15-20 minutes followed by 30 minutes experimenting in the wood.

Children were accompanied by a facilitator to assist them as required, for example, to remind them of their task, scaffold them in their exploration and answer questions they had about the environment. The facilitators' aims were to be there for assistance if required, but to keep in the background as far as possible and allow the children to explore by themselves. Each group was also accompanied by a researcher, recording their movements on video. Children took little notice of the cameras, being absorbed in their different activities.

7. Preliminary findings

The video and audio data collected for each of the pairs of children taking part in the trials are currently being transcribed and analysed. Here, we report on our preliminary observations and general impressions. Overall, despite some early technology problems, the children's participation in the study was regarded as successful. It was felt that the children understood the purpose of the learning activities and were able to carry out scientific enquiry. Moreover, the children were totally fascinated with all the technology provided for them to support them in doing this. They particularly found the probing activity – both the collecting and the subsequent viewing of the data - to be a thoroughly engrossing experience. They also enjoyed using the periscope device, as a way of finding out more about the creatures or plants they had discovered, themselves, in the habitat.

From our experiences with the different pairs we noticed marked individual differences in:

• how the pairs collaborated with each other, the other pairs and the co-located and distant facilitators
• how they took to the various activities (for example, a couple of the children were very keen to use the probing device to explore the moisture levels of their own bodies, including saliva and underarms, while others showed no interest in experimenting on themselves)
• the extent to which they were willing to explore
• their level of confidence and inhibition in touching and interacting with the technologies

When the two pairs of children came back together, they showed much enthusiasm at telling each other what they had discovered and also observing the collection of probes each had collected. They were fascinated with how all their probes had been captured centrally and shown as an information visualisation with the other children's readings. Being able to see both sets of data in this visual way, enabled them to get a holistic picture of the different distributions of moisture and light in the two areas and to make generalisations about the contrasting habitats as to why different types of organisms lived in each habitat and why they would not survive so well in the other.

(i) Exploring and discovering

As mentioned above, one of the most successful outcomes of the first stage of the learning experience was the combined use of the probing device and PDA to collect moisture and light measurements. The pairs of children made frequent probes for both measures, usually with one child doing the probing and the other holding the PDA, reading off the visualisation. Sometimes, both children would look at the PDA screen together, and other times the one holding it would tell the other what they had seen on the screen. The children took many different sorts of readings, e.g. probing different sorts of leaves and bark, widely exploring their habitat to find different areas and things to test in order get a range of levels. They would try to work out initially where in the habitat, would be most moist and light or most dark and dry, and then test their predictions by using the probe device. Having control over the probing device meant the children were actively involved in deciding when and where to take readings. The digital information resulting from their actions was tightly coupled with the activity and the children readily understood the connection between the two.

Figure 14. Using the periscope

The periscope was also highly successful in providing otherwise invisible information in a clear way (see figure 14). Like the probing devices, the children had control over what information they selected to look at and readily understood what the purpose of the periscope was for. The quicktime movies the children found most captivating was of the greatly magnified tiny insects (e.g. weevils) and their trails (e.g. their marks left on a leaf) that they had themselves spotted in the wood. Hence, the movies provided them with a way of finding out more about the physical things they had found. As such, the coupling of the exploring activity with the periscope provided an intuitive and explicit way of integrating different kinds of knowledge.

One unexpected finding was that the incongruous appearance of the periscope in the thicket of the wood informed the way the children approached the device, itself. Unlike the other mobile and pervasive technologies, which were used to present the augmented digital information to the children, the periscope was neither pervasive nor portable. It was a quite distinctly hi-tech "thing" which the children "found" during their journey through the woods. Often the children approached it almost warily, but with great interest – the form itself, and the different elements contained therein seemed to intrigue them (see figure 15). The children generally seemed to first approach the Petri-dishes which protruded like flowers or leaves from the stem of the, otherwise shiny stainless steel and rubber, periscope. The contents of the Petri-dishes stimulated discussion about what each element was and what kind of role it might play in the wood or where it could be found.

Figure 15. Interest in contents in Petri-dishes

Hence, the overall design of the periscope can be considered to be effective. The children were able to deduce what was potentially possible with the device without needing to be led or instructed step-by-step by the accompanying adult supervisors. It also led to further hypothesizing and discussion.

Less successful, was where we had engineered the digital information to be presented to the children in a more pervasive way, i.e. where their bodily presence in an area triggered the digital information to appear on the PDA or sounds to be played through the wireless speakers. In these contexts, the children did not have control, but relied on the serendipity of their movements as to whether they passed in the vicinity of a pinger. The children were never quite certain when this would happen and were often surprised when they heard a sound or saw an image on the PDA screen. Part of our intention of using this pervasive technique was indeed to introduce an element of surprise and the unexpected. Another reason was to augment their physical experience, by drawing their attention to certain aspects of the habitat, they might not have noticed otherwise, and providing relevant contextual knowledge that they could integrate with what they saw. Sometimes this approach worked, and the children related the digital information that was being sent to them on the PDA with what they saw in the wood in front of them (e.g. a real thistle). However, at other times, the children were too engrossed in doing something else and so would miss the beginning part of a voice-over or not even notice a sound. In these moments, the children were often reluctant to switch their attention to what was happening on the PDA from what they were doing.

(ii) Consolidating, reflecting and hypothesizing

Explicit reflection was successfully elicited when the children sat down together in the den area and were able to access and interact their light and moisture readings. Tracking recording and re-presenting the light and moisture readings the children had taken, proved to be a highly effective way of augmenting their physical experience of collecting data, providing a good overview of where the children had each been and what the big picture looked like, enabling them to recognize the differences between findings and habitats. Hence, this session enabled the children to consolidate the knowledge gleaned from the activities they had been partaking in the wood (see figure 16).

Figure 16. Looking at visualization in the den area

The session where children used tagged tokens to aid their recall and explain to one another was successful in enabling them to combine the chunks of information they had received on the PDAs and experienced in the wood in the correct logical order. In particular, they were able to re-represent the interdependencies between the various organisms that populated the habitat. However, the activity was not as engaging as the 'probe-based' consolidating activity, which involved the hypothesizing and visualising of the readings collected. This appears to be due to the weaker coupling between how they got the information in the wood and what they were required to do with it subsequently back in the den. Whereas the collecting of probe readings was a highly engaging physical activity, that the children were in charge of, themselves, deciding where and when to make readings, the receiving of digital augmentation of the processes in the habitat, was essentially a passive 'reading' task, that was totally dependent on the children walking past a 'hidden' point in the habitat. Hence, the information the children were using to re-represent what they had seen, found out and explored in the den did not have the same kind of physicality or ownership associated with them as did the probe 'readings' and the subsequent interactions with the global visualisation of them. Again this emphasises the importance of the need for a close coupling between physical activity and digital feedback, but also the importance of taking a major part in the collecting and discovering.

(iii) Hypothesizing and experimenting

When introduced to the tokens that were used to explore potential changes to the habitats with the introduction of new species, the children were able to make appropriate predictions. This then facilitated them to think and talk about the processes involved and interdependencies. Handling the artefacts was engaging and fun for them, and using the periscope was successful in providing animations of different scenarios that confirmed their predictions of what would happen as a result of introducing other species into the wood (see figure 17). The same was true when they went to the clearing area and took further probes to confirm their hypotheses of what would happen if the area was flooded.

8. Discussion

Overall, our project was very successful on a number of levels, including providing highly engaging and novel learning experiences for children. By abandoning the conventional view of IT and education, and reconceptualising *information* and *technology* in terms of 'digital augmentation of physical activities', we were able to design technology-mediated learning experiences that were quite different from the conventional 'search', 'cut and paste', 'paint' and 'write' type educational tasks typical of desktop applications. To this end, we used a range of pervasive and mobile technologies to provide contextually relevant digital content, that was triggered by different kinds of physical activities (e.g. walking, probing, placing). Many lessons were learned regarding the technological, practical and design concerns for moving outdoors (see Harris et al, 2002).

Figure 17. (i) Collaborative experimenting with tagged artefacts (ii) and observing the outcome

A key issue our research has raised is the pros and cons of using different ways of delivering digital content to users/children while moving around in an open space, looking at the physical environment around them, both with a naked eye and ear and through using various devices. Unlike, sitting in front of a computer or TV screen, where children's attention is largely drawn to one focal point, we designed the experience so that their attention would be constantly switching between different demands and things going on. As well as navigating the area, looking and hearing at what was going on around them and talking to each other, we required them to listen to unexpected sounds playing from hidden wireless speakers, other times to talk to the distant facilitator about what they had discovered, other times taking a reading, while other times to look at the content appearing on the PDA. At first, they found these overlapping and competing demands a bit bewildering and would leave what they were doing in 'mid-sentence' and move onto the next demand. Once the children got the hang of the different demands, however, they started to decide for themselves more how to deal with the interruptions and different demands on their attention. For example, if they were taking a reading or listening to a voice-over and the facilitator on the walkie-talkie started talking to them, they would choose to ignore it till they had finished what they were doing.

We were also concerned that they might be glued to the PDA screen while walking around, in anticipation of the next piece of information popping up. However, this was not the case at all; all children were as interested in what was happening in the physical world around them (noticing spiders, berries, slugs, deer droppings etc) as the digital world we had augmented it with.

Hence, the issues of control and attention are important when considering how to design the way augmented digital information is accessed and perceived. In the Ambient Wood project, we experimented with different ways, from pervasive to direct control. Our findings suggested that children much preferred physically discovering things in the wood (i.e. they were in control of the discovering) and then learning more about them through the various digital augmentations – rather than the other way round (i.e. the pervasive environment decides what to show them). This suggests to us that technologies should be designed that augment learning through a close coupling of action and feedback. For example, when a child finds something that is of interest to them, e.g. moss or dead leaves on the ground, they should be able to discover more about them then and there. In this way, the exploration would be driven by them and the information they received would be directly related to what they are exploring. This could be achieved by providing other kinds of tools and displays, like the periscope, where the children match what they had found against a set of pre-stored tokens representing typical items found in that habitat, and place them on an associated tag reader and display. Other kinds of displays could be designed that allow them to see more of the invisible in context, for example, an underground seeing device, that could allow them to see the creatures that live underground and a tree seeing device that allows them to see the processes occurring inside a tree.

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References

Bruner, J., Jolly, A. and Sylva, K (1976) *Play - Its Role in Development and Evolution*. New York: Basic Books, Inc.

Bruner, Jerome. (1979). *On knowing: Essays for the left hand*. Cambridge, MA: Harvard University Press.

Cassell, J. and Ryokai, K. (2001). "Making Space for Voice: Technologies to Support Children's Fantasy and Storytelling." Personal Technologies 5(3): 203-224.

Colella V., Borovoy R. & Resnick M. (1998). Participatory Simulations: Using Computational Objects to Learn about Dynamic Systems. *Proceedings of the CHI98*, Los Angeles, CA, 18-23 April 98, 9-10.

Ishii, H., Ullmer, B. (1997). “Tangible bits: Towards seamless interfaces between people, bits and atoms.” *Proceedings of CHI’97*. ACM Press. 234-241.

Price, S., Rogers, Y., Scaife, M. Stanton, D., Neale. H. (2002) Using ‘Tangibles’ to Promote Novel Forms of Playful Learning. To be published in *Interacting with Computers* Journal. In press.

Randell, C. and Muller, H. (2001) Low cost indoor positioning system. In Gregory D. Abowd, editor, *Ubicomp 2001: Ubiquitous Computing*, p. 42-48. Springer-Verlag

Resnick M., Martin F., Berg R., Borovoy R., Colella V., Kramer K. & Silverman B. (1998) Digital Manipulatives: New Toys to Think with. *Proceedings of the CHI 98*, Los Angeles, CA, 281-287

Scaife , M. and Rogers, Y. (2001) Traversing between the digital and the physical: what does it mean? In Workshop Proc on *Moving between the physical and the digital*, I3 Spring days, 24th April, Porto, Portugal.

Rogers, Y., Scaife, M., Harris, E., Phelps, T., Price, S., Smith, H., Muller, H., Randal, C., Moss, A., Taylor, I., Stanton, D., O’Malley, C., Corke, G., and Gabriella, S. (2002) Things aren’t what they seem to be: Innovation through technology inspiration. *DIS 2002 Designing Interactive Systems Conference* ACM 2002

Schön, D. A. (1991) *The Reflective Turn: Case Studies In and On Educational Practice*, New York: Teachers Press, Columbia University.

Segal, B. and Arnold, D. (1997) Elvin has left the building: A publish/subscribe notification service with quenching. *Proceedings AUUG Technical Conference (AUUG'97*), pp. 243-255 (September 1997)

Soloway, E., Guzdial, M., Hay, K., (1994) Learner- Centered Design: The Next Challenge for HCI, *ACM Interactions*, April.

Stanton, D., Bayon, V., Neale, H., Ghali, A., Benford, S., Cobb, S., Ingram, R., Wilson, J., Pridmore, T. and O'Malley, C., Classroom Collaboration in the Design of Tangible Interfaces for Storytelling, in *Proceedings CHI 2001*, pp. 482-489, ACM Press

Stanton, D. and Neale, H (2002). Designing mobile technologies to support collaboration. Submitted as *Equator internal report*.

Tapscott, D. (1998) *Growing Up Digital: The Rise of the Net Generation.* New York. McGraw Hill.

Thompson, M.K., Weal, M.J. and Michaelides, D.T. (2002) MUD Slinging: Virtual Orchestration of Physical Interactions. *Technical Report for the Equator 2002 Conference*, October 2002 (see http://www.ecs.soton.ac.uk/~mkt/20021004-ambientinfra.pdf)