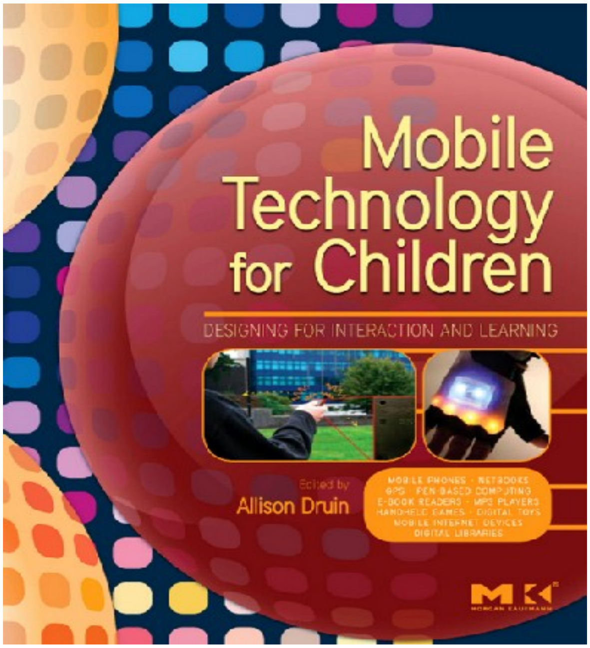

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SECTION 1
The Landscape

CHAPTER 1

How Mobile Technologies Are Changing the Way Children Learn

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In this chapter we describe how mobile technologies are transforming learning. We start by taking stock of the burgeoning area of mobile learning research and describe both the benefits and challenges of using mobile technologies to support children's learning. We explain what is meant by mobile learning and provide a review of four core developments in the area: physical exercise games, participatory simulations, field trips, and content creation.

INTRODUCTION

Children have always loved running around, whether chasing one another through a shopping mall, darting along a beach, or playing hide and seek in the woods. Nowadays, with a selection of mobile technologies stuffed in their pockets or around their necks, they can do more than simply enjoy the moment. With a digital camera or an iPod at the ready, they can take pictures or record sounds they encounter during their outdoor pursuits. They can tag these artistic creations with comments and other personal details and then upload them to Facebook or another social Website to share them with their friends, teachers, or family.

Specialized handheld tools such as digital probes are also changing the way children explore and relate to their "neck of the woods." For example, they can measure the level of carbon monoxide being emitted from their school bus as it chugs its way past their homes, schools, and playing fields. They can update their data and compare it with similar types of data collected by children in other parts of the world, creating an online global map that shows school bus pollution hotspots.

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Another creative development is a digital necklace that children can wear as part of a simulation game in which they each pretend to be a virus. As the children move around a physical space, they try to avoid or come into contact with each other, mimicking the way viruses spread a common cold. The sensors on their necklaces do the spreading, the outcome of which is depicted on a computer display. The contacts made by the viruses appear as a brightly colored pattern that children can analyze and through which they can trace their own spreading trajectories.

These are just a few examples of ways in which the new generation of mobile technologies is changing the way children learn. Not only is mobile learning highly engaging, it also provides children with novel ways of relating their physical experiences to abstract knowledge, from running around a playground to understanding what a carbon footprint is. These innovative forms of physical digital switching are thought to lead to a more in-depth understanding of a topic. They also increase children's opportunities to make connections between their observations and ideas that can help them grasp difficult concepts.

But how do mobile learning applications compare with PC-based, educational software programs that are now commonly used in schools to teach subjects such as math, language arts, or science? An important difference is the way fixed and mobile computers are used. PCs are *deskbound* and ideally suited to individual or pairs of children sitting in front of a computer screen, focusing their attention on solving a problem or completing a set task during a lesson. Mobile technologies are *handheld* and ideally suited for relatively short bursts of use (such as entering and comparing data or looking up and reviewing information) while involved in *foregrounded* physical activities, such as exploring a forest. In other words, PCs support sedentary children working primarily on digital tasks in the classroom or home, whereas mobile technologies support embodied children engaged in a diversity of physical activities and contexts.

An advantage of learning while mobile is that children often become more motivated and engaged than when staring at a PC while sitting still. But more significantly, mobile learning opens up many new opportunities for ways in which children can learn. What appear to be disparate activities can now be integrated over time and space. By making more connections between their emergent ideas, prior knowledge, and ongoing observations of the world, children are starting to view and understand the world differently. This development in educational technology represents a major shift in the way computers can be used to stretch children's minds.

MOBILE LEARNING

Several researchers have suggested that we are entering a new era of technology-enhanced learning, characterized as *mobile learning* (e.g., Sharples et al., 2005; Tatar et al., 2003), *seamless learning* (Chan et al., 2006), and *ubiquitous learning* (Rogers et al., 2005). Central to these notions is the idea that mobile technologies can be designed to enable children to move in and out of overlapping physical, digital, and communicative spaces. This mobility can be achieved individually, in pairs, in small groups, or as a whole classroom together with teachers, mentors, experts, parents, professionals, and others (Chan et al., 2006). It is assumed that mobile technologies provide continuity across various learning experiences, enabling children to make connections between what they are observing, collecting, accessing, and thinking about over time, place, and people. For example, a child might use his iPhone to chat with a mentor in *Second Life* about biodiversity while sitting on a bus and then, based on the expert's suggestions, join in a snail hunt in his local park, take photos with his phone, tag the snails' location using GPS coordinates, and then send the data, with a suggestion as to what the snails are, to an online Website on biodiversity. The biologists monitoring the site could then send a message back to him verifying whether his identification of the snails was correct and could then add his data to a national database that the child could subsequently show to his biology teacher at school.

There is an ongoing debate about how this kind of mobile learning can encourage new forms of social interaction, thinking, or reflection (e.g., Pachler, 2007; Sharples et al., 2008). As shown in the previous example, being able to communicate with others what one is thinking and seeing is an integral part of learning. Through explaining to others and representing information via various media, children can be made aware of their own discrepancies in understanding, enabling them to revise their understanding (*c.f.* Chi, 1997). "One way in which learners may gain from working closely on a problem is by being required to make their thinking public and explicit" (Crook, 1994, p. 133). Collaboration can increase awareness, which in turn can enable children to reflect on what they are currently engaged in.

Another concern is whether the focus should be on the technology being mobile or the extent to which the learner is mobile (Traxler, 2005). In some contexts, it is important that the activities are highly physical; in others, the portability of the mobile technology is more critical. For still others, it is the way the device is used among a group of children during a task that is important. If children are each given a mobile device, this can promote working by themselves, whereas if they have to share one, they are required to collaborate more.

Several researchers have sought to explain the principles behind mobile learning (e.g., Sharples, 2005). Some have proposed existing learning theories, such as constructivism; others have suggested that new theories are needed. Most studies to date that investigate mobile learning have been based on or informed by constructivist theories of learning, drawing from Vygotsky (1978) and Papert (1980). These propose that we construct knowledge and meaning from our experiences and that this is best achieved through doing or making things. Another approach has been to cast the theoretical underpinning of mobile learning more broadly in terms of embodiment (e.g., Marshall and Rogers, 2009; Price et al., 2009). *Embodiment* refers to the interactions and conversations that happen in our physical and social worlds and provide meaning (Dourish, 2001). A focus is on the intricate relationship between perception and action and the way that bodily experiences inform our understanding of abstract concepts. For example, abstract concepts, such as *above*, *below*, *up*, and *down* are understood through being physically experienced in the world (Lakoff and Johnson, 1980). Given that mobile learning typically involves acting and communicating in a physical and social world, rather than constructing things per se, it follows that ideas arising from embodiment may provide a more extensive account.

MOBILE LEARNING ACTIVITIES

A number of mobile applications and tools have been developed to augment learning. We describe these here in terms of four types:

- Physical exercise games
- Participatory simulations
- Field trips and visits
- Content creation

Physical exercise games

Mobile technologies have been incorporated into a number of physical activities to encourage children's understanding of abstract phenomena. For example, *FloorMath* combines a sensor-embedded floor mat with a visual representation of the number system that appears on an adjacent screen (Scarlatos et al., 1999). When children walk up and down the squares, the corresponding numbers change on the screen. Walking the numbers is thought to make the activity more meaningful, helping children to see and understand abstract concepts in a new way (Scarlatos, 2006, p. 295). Similarly, *SmartStep*, developed by the same researchers, requires children to play hopscotch, skip, and count at the same time when practicing basic math skills (Figure 1.1). This combination of physical and mental activities is meant to hone motor skills, pattern recognition, rhythm, and coordination.

Physical exercise has also been coupled with other kinds of informal learning. Spikol and Milrad (2009), for example, developed a game called *Skattjakt* (*Treasure Hunt* in Swedish) that encourages teams of teenage children to simultaneously run around a physical environment, in this case a castle located on the university campus, to solve a mystery using mobile devices. The game design was inspired by orienteering, a traditional Scandinavian running sport involving navigation. Instead of mapping the physical exercise directly to the learning of abstract concepts, it is loosely coupled to orienteering skills, such as reading maps, and learning about history and team collaboration. Cell phones present text and audio-based clues at particular times, showing where the teams are on an interactive map of the whole area. Teenage girls playing the game readily understood the connection between the physical exercise demanded of them

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FIGURE 1.1
(a) *FloorMath* and
(b) *SmartStep* physical and digital interfaces for learning math. Lori and Toni Scarlatos, Stony Brook University.

and the practice of orienting skills. For example, one girl commented: "There is a different feeling running when you have an added reason to do it."

Nintendo Wii applications are also beginning to be used for learning various physical and cognitive skills. Kahol and Smith (2008) found that playing *Marble Mania* improved the dexterity skills that are needed for performing surgery; Vannoni and Straulino (2007) showed that children were able to learn about force, velocity, and acceleration through using a Wii remote to measure acceleration of a swinging pendulum.

All these applications use mobile technologies to bootstrap physical activities (e.g., walking, running) with learning math, physics, or other cognitive skills (e.g., orienteering). At the same time, if the physical exercise is designed to be strenuous, children's health can equally benefit through the children having to run, walk, or cycle while learning.

Participatory simulations

A *participatory simulation* is a game in which sensor-based devices are worn or carried by children to enact a complex phenomenon, such as epidemiology. Each child plays the role of an element (e.g., a virus) at ground level that they then view at bird's-eye level to see how their individual contribution affects the whole system (Colella, 2000). Participatory simulations have been developed to represent a number of systems and have been played out in various settings, including classrooms, museums, and playgrounds. They include (1) dynamic systems, such as a flu epidemic; (2) embedded naturally occurring phenomena, such as an earthquake; and (3) imaginary worlds, such as a magical place.

Dynamic systems

Thinking Tags was one of the earliest prototype systems that used homemade wearable computers to simulate the spread of an epidemic (Colella, 2000). Participants wore the mobile computing devices around their necks. Light-emitting diodes (LEDs) lit up on them to indicate how many people each participant had been in contact with (Figure 1.2). By pretending to be a virus, each child discovered how dynamic events changed as a consequence of his or her behavior and on this basis made real-time decisions about what to do next—for example, discover more, control, prevent, or manage the events.

More recently, a genetics simulation was developed using the *Thinking Tags* technology to explore concepts related to genetic inheritance, such as genotype and phenotype (MacKinnon et al., 2002). Each tag was programmed with a specific genotype that was not initially known to the students. The students were simply told that their eye color (phenotype) was either green (dominant) or red (recessive). Their task was to meet with other tagged children and determine whether the eye color of their "virtual offspring" would be green or red by observing the pattern of red and green LEDs that lit up on meeting. Studies of students using the mobile tags showed that the technology pushed them to become involved in the simulation, resulting in much discussion.

Thinking Tags have also been used with very young children to help them learn about dental hygiene. According to many dentists, children find it difficult to understand how eating candy and drinking sugary drinks can cause their teeth to rot. Tooth decay caused by the buildup of sugar is a difficult concept for young children to learn. Instead of being taught about dental health the traditional way, five-year-old children used *Thinking Tags* to experience improving

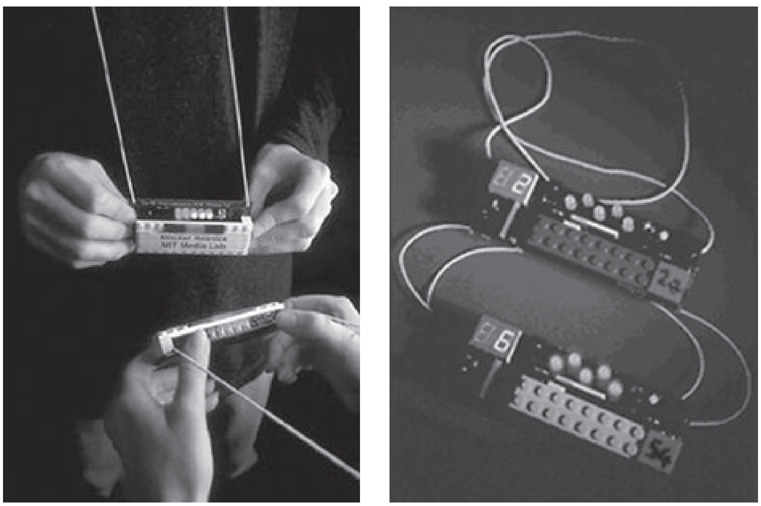

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FIGURE 1.2
The wearable devices used in the *Thinking Tags* participatory simulation (V. Colella, R. Borovoy, and M. Resnick, 1998).

or decaying dental health (Andrews et al., 2003). In this context, the digital tags were used to simulate the decay process, enabling the children to experience it firsthand and then talk about it. The technology provided a much more accessible way of learning about a difficult topic.

More recently, cheaper and more robust personal digital assistants (PDAs) have been used to replace the fragile and expensive tags, with similar learning benefits (Klopfer et al., 2002). The PDAs have other advantages in that children can access further information at the moment they bump into each other, and their interactions are automatically transmitted to a large public display and added to a composite visualization of all the children's movements, representing the dynamic system being acted out in real time.

Embedded naturally occurring phenomena

Mobile technologies, in combination with other physical artifacts, have been used to simulate naturally occurring phenomena. The most well-known example is *RoomQuake*, which simulates seismic events in a classroom (Moher et al., 2005). In this system, the children do not act out the event; rather, they observe aspects of it as it happens on mobile devices, then carry out various measuring and inquiry processes. Pocket PCs are strategically placed at stations throughout the classroom. Throughout a normal school day, seismic events are programmed to randomly occur, to make the simulation more authentic. Their beginning is signaled by low, rumbling sounds, at which point the class breaks up into small groups to record dynamic readings of the simulated earthquakes. Children are more than happy to stop what they are doing (for example, math) when alerted by a rumble and quickly move to the various stations. The recorded readings are then used to create a physical model of the earthquake; string and Styrofoam balls are hung from the classroom ceiling to physically show the epicenter of the digitally recorded earthquakes (Figure 1.3). Children who took part in this simulation became competent at interpreting seismograms and understanding how to perform complex analytical tasks such as trilateration.

The *Environmental Detectives* game was developed to simulate part of the environment under toxic threat (Klopfer et al., 2002). It required groups of students to solve a problem under various temporal constraints by moving around a physical space and reaching conclusions using information they detected on their mobile devices. The students had to investigate the

FIGURE 1.3
Children using Pocket PCs to take measurements of the simulated seismic event in *RoomQuake* (T. Moher, S. Hussain, T. Halter, and D. Kilb, 2005).

spread of a chemical spillage and create a remediation plan. The spill was simulated on location-aware Pocket PCs that could also be used to sample virtual chemical concentrations in the groundwater using virtual drills. This type of real-world simulation is thought to enable academic learning to be coupled more closely with students' physical, lived world (Squire and Klopfer, 2007).

Savannah was designed as another game to be played outdoors to develop children's understanding of animal behavior through their interactions on a virtual plain (Benford et al., 2005; Facer et al., 2004). Global positioning system (GPS) enabled handheld computers presented a virtual savannah that digitally overlaid a school playing field and was populated by animals that would normally be found there. Each child took on the role of a lioness and had to hunt other animals, such as antelopes, to survive. This involved the children working in teams, as though they were hunting as a pack. As they moved around the playing field, the children's mobiles kept track of where they were and popped up pictures of their surroundings, including animals that were close by (Figure 1.4). The children's energy levels were also shown using simple graphical representations, indicating when they needed to eat to stay alive. Remote facilitators occasionally sent messages to them via the mobiles (e.g., "You are hungry") to keep them in the game. The children then returned to the classroom to talk about their experiences and learn more about the animals' behavior. An evaluation of the game suggested that it encouraged self-directed learning. However, the children sometimes found it difficult to match up the images of animals

FIGURE 1.4
Screen shots from the virtual *Savannah* game showing (a) prey and (b) players' energy levels. Savannah @ Futurelab, Mobile Bristol, HP Labs, BBC Natural History Unit.

they saw on their PDAs with the empty playing field. A considerable amount of imagination was required to play the game.

Imaginary worlds

We designed *The Hunting of the Snark* to explicitly encourage imagination and reflection, but this time in very young children (Rogers et al., 2002; Price and Rogers, 2004). Pairs of children, aged between 6 and 8, had to discover as much as they could about an imaginary creature called the Snark—its appearance, its likes and dislikes—by physically interacting with the creature in various activity spaces. The children had to perform certain kinds of embodied actions in these spaces, such as flying, dancing, walking, and feeding. The Snark never appeared in its entirety but only as glimpses in response to the children's physical actions (Figure 1.5). The Snark responded by crying, laughing, or showing appreciation or disgust to what it was fed. These emotions were represented using simple abstract animations to encourage the children to use their imagination.

Children who played the game were fascinated by the animated representations of the Snark that surfaced in the activity spaces and tried to work out how their physical actions caused them to appear. After the game, the children often gave lengthy narratives of the Snark's personality and behaviors that were based on their different glimpses when flying with, dancing with, and feeding it.

Participatory simulations, in their various forms, have been successfully designed to create highly engaging experiences that allow children to explore various aspects of a system, whether an epidemic or an invisible world. However, this success requires children "buying into" the game to get the most out of it. Most of the time children, especially younger ones, will suspend disbelief so that they can experience what it is like to be a virus, a detective, or a lion. Occasionally

a b

FIGURE 1.5
Children physically interacting with the digital Snark. (a) Flying with the Snark as a happy colored dancing square. (b) Feeding the Snark a token cookie at a pond, with the result that the creature shows appreciation. From "Hunting of the Snark," EQUATOR, 2003 (http://www.equator.ac.uk/).

breaks occur between the imagined and the virtual representations appearing on the mobile devices, but children are good at papering over the cracks.

Wearing or holding a mobile device also provides children with relevant and valuable information they can act on in the moment that can help them make more informed decisions than if they were playing the same game without any mobile computer support (Colella et al., 1998; Colella, 2000; Wilensky and Stroup, 1999). The key is to provide the right level and kind of information when it's needed, to provoke the children to think on their feet and subsequently reflect on their actions. Similar to the physical exercise games, a sense of ownership, as well as participation, in the simulation is important to the success of the learning. Children have a quite different experience when they are able to interact with and analyze data that they helped create as part of the simulation, whether a virus as its spreads or an earthquake as it develops, compared with watching the process unfold on a computer screen. In sum, participatory simulations are most effective when children can readily step in and step out of them and can switch between being part of the simulation and being apart from it.

Field trips and visits

Another popular use of handheld technologies has been to augment children's field trips and visits to museums and other places of interest (e.g., Gay et al., 2002; Grant, 1993; Hine et al., 2004; Layman and Krajcik, 1992; Metcalf and Tinker, 2003; Rogers et al., 2005; Soloway et al., 1996; Roschelle and Pea, 2002; Yeh et al., 2006). In these settings, the mobile devices provide historical, environmental, or cultural information about what is being observed that is relevant to the ongoing activity but that is not available in the environment. The provision of such contextualized information helps children develop their investigative skills (e.g., Loh et al., 2001; Rogers et al., 2005; Tinker and Krajcik, 2001).

A project that pioneered this approach to mobile learning was *Ambient Wood* (Rogers et al., 2004). We designed a field trip with a difference; children, aged 10–12, had to explore a woodland and, at certain times, access, discover, or receive relevant sources of digital information using an assortment of embedded and mobile technologies. One example was a special probing tool that the children used to collect real-time measurements that resulted in simple visualizations of light and moisture levels being shown on a PDA screen (Figure 1.6). The children found the tool highly engaging and probed many aspects of the woodland (including even parts of their own bodies). They often went in search of extreme measurements: trying to find the wettest and driest parts or the brightest or darkest parts. They took turns to either probe or read the outcome on the PDA. After taking a reading, the children would suggest to each other alternative places to go to confirm or refute their hypotheses about the readings they were getting. They also suggested to each other where to take the next reading; again, this involved them making suggestions about what readings they

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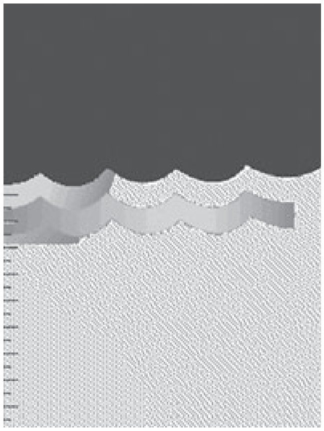

b

FIGURE 1.6
(a) The probing tool with a reading of high moisture level showing on (b) the PDA as part of the *Ambient Wood* project (Y. Rogers, S. Price, C. Randell, D. Stanton-Fraser, M. Weal, and G. Fitzpatrick, 2005).

expected to get and then testing predictions about the environment. In addition, probing sometimes led to the discovery of new plants (e.g., moss) when the children were looking for places or organisms that would provide them with different readings.

The PDAs also transmitted to a mobile server their probe readings and data on where they had been taken. These readings were combined and rerepresented as interactive data points on a bird's-eye map of the areas the children visited. This bigger picture was later shown to the children via a shared display situated in a makeshift classroom in another part of the woodland. The visualization could be clicked on to bring up the same readings that the children had probed and viewed on their respective PDAs. They were fascinated by their data being presented in both forms and talked openly to each other about what they had collected and where, reflecting on their probe readings while still in the woodland.

The PDAs also presented images of plants and animals to the students at pertinent times, to draw their attention to particular aspects of the physical environment. Location-based pingers were situated at predetermined places of interest in the woodland, and when a child with a pinger receiver (carried in a backpack) was detected, an image, such as a thistle or butterfly that could be found in that location, appeared on the PDA. While exploring the woodland the children communicated with a remote facilitator through the use of walkie-talkies, reporting on what they had discovered, its significance, and what they planned to do next. The facilitators also reciprocated, asking them what they were observing and measuring while also helping to guide their inquiry processes.

The learning activities that took place in *Ambient Wood* were impressive (Rogers et al., 2005). Collaboration and self-directed inquiry processes were much in evidence. In particular, the children used the mobile devices to make predictions, generate hypotheses, analyze their data *in situ*, and look for patterns and relationships between particular instances of data. Furthermore, the children often reflected on their actions while exploring and, when back in the makeshift classroom, continuously made links among location, organisms, and biological processes.

However, it has also been observed that children can get distracted when given a mobile device to use in support of another activity. In particular, children can become more isolated from others around them, listening to or reading what is on the mobile device. For example, in a museum visit, Hsi (2002) found that children tended to focus more on interacting with the mobile devices they were given at the expense of interacting less with hands-on exhibits and each other. Children may also resort to working by themselves if given one mobile device each to use; this contrasts with groups without handheld devices who tend to work things out together (Semper and Spasojevic, 2002). One way to prevent children from working alone, if it is considered important that they collaborate, is to make them share a mobile device and interact with each other to progress with their task.

In some instances, mobile technologies can be used effectively on field trips and museum visits to augment children's learning by providing access to information during an activity at poignant moments that would otherwise have been overlooked. However, it is important to ensure that children do not focus their attention too much on the device; otherwise, they can miss seeing what is happening around them. Instructor guidance and the design of structured learning activities can help children switch between the mobile device and the physical environment.

Content creation

Another development in mobile learning is to cocreate content *in situ* (Brun et al., 2007), such as story writing and filmmaking. The idea is to enable development of richer narratives that reflect events in which the children have been engaged, such as a visit to a city, a historic site, or a zoo. Typically, the creative process entails sharing, sending, collating, and rerepresenting information, such as photos, audio, and notes, among groups of children (Järvelä et al., 2007; Rost and Holmquist, 2008). Mobile Web applications such as Flickr, Twitter, and Facebook can be used to upload the content the children create so that others can see and comment on it.

An assortment of cell phones, digital cameras, laptops, and PDAs may be used to create content while exploring a particular place. However, this can sometimes be cumbersome to manage. An alternative is to develop an all-in-one handheld computing device that incorporates all the content creation functions. One example of this is ButterflyNet, which lets students capture, access, share, and transform photos, notes, and readings (Yeh et al., 2006). Though it has been found useful and usable by students recording and capturing data in the field, it is unclear as to whether a multifunction handheld tool is preferable to using a set of lightweight tools that support specific functions. On one hand, children might find it easier to integrate their *individual* work more easily when they're using one mobile tool. On the other hand, it can reduce the need for children to share devices and representations in their learning activities, which, as already noted, is instrumental to collaborative learning.

A benefit of enabling children to take photos *in situ* and to record other aspects of the environment is to make them select relevant information that is personally related or related to the task, record it, and then rerepresent it through publishing it on a Website or showing it in class. This requires creating a rich form of narrative that "tells a story" around the children's recorded artifacts, which can enable them to make connections between disparate activities. This kind of externalization, that is, articulation and explanation, is known to be beneficial for learning (Scaife and Rogers, 2005). But a danger is that children may choose to record things that are attractive rather than coherent with the learning task and so construct a poorly integrated narrative. Similar to augmenting field trips, it is important that structure is provided in mobile content creation activities through the assignment of tasks and roles.

THE BENEFITS AND CHALLENGES OF MOBILE LEARNING

Our review of the literature on mobile learning has revealed three main benefits, compared with the more sedentary PC-based learning.

First, using mobile devices in the wild can be highly motivating, increasing children's engagement with their learning. This is especially so when the physical activity involves an element of the unknown, where children have to discover information to progress the task through their own physical actions. Second, being mobile while learning can encourage children to participate more, facilitating a diversity of key social and cognitive processes. Third, it offers quite different forms of information flow (ways and means of accessing information) and information management (ways of storing, recording, and reusing information) compared with the conventional use of PCs, enabling children to better integrate their ideas and knowledge with ongoing physical activities (Rogers and Price, 2008).

We have also identified three main challenges in using mobile technologies to augment learning: first, avoiding information overload; second, preventing children from becoming too distracted by their mobile devices; and third, constraining the design of the learning experience so that children do not work largely by themselves, if the desired goal is for them to collaborate.

Let's consider how these factors can inform the design of mobile learning activities. Many mobile learning experiences are well suited to supporting active exploratory activities in which children can make their own discoveries about a concept being learned. Physical exercise activities can be designed to allow children to explore the effect of their actions on different abstract representations, to support conceptual understanding. Participatory simulations can be designed to enable children to act out individual roles and see the effects of their physical actions in relation to other children's actions on a combined digital display. Augmented field trips can be designed to enable children to collect data from the environment and view it as part of a larger scientific pattern. Content creation activities can be designed to be more meaningful, enabling children to construct richer and more complex narratives.

Common to these mobile learning activities is switching between the specific experiences of an activity and a global view of it. One of the potential benefits of moving between different levels is the opportunities it affords to do more "joined-up thinking." By this we mean making connections among observations, ideas, and previous knowledge. For example, augmented field trips enable children to connect contextually relevant information accessed via a mobile device with their partially formed ideas and understandings. Through integrating the accessed digital information with their observations, they can begin to make generalizations from them. Observations made in the environment can also be closely combined with information accessed on a mobile device in the same location and time. This means that children do not have to "hold back" from pursuing further thinking or inquiry until they have returned to the classroom, where they can look something up (but where they often forget what they have noted in the field) and instead can progress with their reasoning and thinking while still *in situ*. If certain kinds of relevant information are brought to the center of children's attention at critical moments, they can use it to formulate inquiries. In addition, multiple pieces of data can be integrated, tracked over time, analyzed, and used as a basis from which to reason about further incoming data.

Data can also be automatically collected, logged, aggregated, and stored in ways that can be made reaccessible to children, either in that setting or subsequently in a different one. Being able to revisit such data, especially since it has been personally collected, can aid understanding of the "difficult stuff" (Scaife and Rogers, 1998); for example, data points that are aggregated and transformed into abstractions, such as information visualizations and trend graphs, become more accessible and meaningful when analyzed if children have had some personal involvement in their creation.

It is important to design mobile learning experiences so that they are not too bewildering or overly complex. In particular, children could find it difficult to switch between digital content and the physical world in the ways anticipated by the designers. For example, they might focus their attention on the mobile device at the expense of what is happening around them. Teachers or facilitators could also face difficulties when confronted by the increase in number of choices they have to make—for example, how to manage the interplay between physical and digital interactions and how much control or guidance to exert over the children's activities as they explore a physical space.

Guidance by teachers or facilitators, together with roles for the children and structure in the activities, are key components. The participatory simulations would end in chaos if it were not for the instructors' and designers' careful orchestration of the learning activities. The same is true for physical exercise games: "Without the constant guidance of a teacher, students […] easily become distracted, confused, or frustrated" (Scarlatos, 2006).

More generally, the extent to which devices are shared raises the question of what is an optimal number of mobile devices to distribute among a group of children. In the *Ambient Wood* project, pairs of children shared devices, resulting in the children communicating their findings with each other. Now that the price of mobile phones is much lower, it is possible for every child to have one and hence all be able to interact with a particular mobile learning application. However, this approach might be counterproductive because it would mean that children no longer need to share or request information from each other.

An alternative strategy is to design the learning activity to be explicitly structured so that each student takes on a specific role, requiring them to relay certain kinds of information or messages to others at certain times. The role of remote (and even agent) facilitators could also be made more prescriptive, where facilitators provide cues, prompts, and feedback when it is deemed that the students need a particular kind of support. It remains to be seen, however, whether providing more or less structure in the learning activity and allotting one mobile device per child result in enhanced collaborative interactions.

In sum, mobile learning offers new possibilities for transforming learning that can extend the way children understand their world and how they communicate this understanding, and can reveal how this understanding relcal can equip them with the ability to cope with an increasingly changing world. Mobility should not only be about learning "on the go" or "anytime, anyplace" but about providing opportunities for making important connections or more "joined-up learning."

Connecting to you

- Mobile technologies for learning can couple physical activities with social and cognitive development.
- Communication can change when children use mobile technologies.
- An increase in joined-up thinking and reasoning can result from mobile learning activities.
- Mobile technologies can be used to support children's learning through physical games, participatory simulations, field trips, and content creation.
- There are three main challenges in using mobile technologies to augment learning: avoiding information overload, preventing children from becoming too distracted by their mobile devices, and constraining the design of the learning experience so that children do not work largely by themselves.
- It is important to design mobile learning experiences so that they are not too bewildering or overly complex.
- Mobile learning can lead to meaningful switching between multiple kinds of experiencing and abstracting.

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