Beyond Current Horizons Review

Theme/area: 2

Embodiment/the body, knowledge, creativity and communication

Sara Price, George Roussos*, Taciana Pontual Falcão, Jennifer G. Sheridan

London Knowledge Lab, Institute of Education, 23-29 Emerald Street, London, UK. WC1N 3QS

*London Knowledge Lab, Department of Computer Science, Birkbeck College, 23-29 Emerald Street, London, UK. WC1N 3QS

E-mail: s.price@ioe.ac.uk, g.roussos@dcs.bbk.ac.uk, t.pontual@ioe.ac.uk, j.sheridan@ioe.ac.uk

1. Introduction

Embodiment in the context of this review centres around the notion that human reasoning and behaviour is defined by our physical and social experience and interaction with the world. Although concepts of embodiment are not new, current theoretical trends are placing more importance on the role of embodiment in understanding human behaviour. Several factors have contributed to this change, not least the emergence of technologies that enable radically different forms of interaction with them and through them, than traditional desktop computing. Ubiquitous computing technologies can be integrated into the environment, in unobtrusive and 'seamless' ways. This offers opportunities to build on familiar real world 'natural' interaction practices through various forms of digital augmentation, e.g. enabling interaction with contextually coupled information. New technologies also provide opportunities for interaction and learning to be more active, hands-on, directly related to physical contexts, with new forms of communication and collaboration promoting socially mediated learning, and new tools that aid external cognitive support. Furthermore, graphical interface development extends possibilities for more complex interaction, sense of presence and immersion or embodiment in virtual environments, bringing new 'spaces' for learning.

Psychologists and philosophers have long argued for the important role of sensori-motor interaction with the world for cognitive development (Piaget, 1972; Vygostsky, 1978; Clark and Chalmers, 1998), but with the growth of ubiquitous computing the possibility for enhancing physical environments and physical interaction have brought discussions around embodiment to the forefront, and driven forward research into understanding the interaction between mind, body and the environment. Collectively, these views and possibilities have wide-reaching implications for education, particularly in terms of the potential for influencing the way we teach and learn, and how education may be organised. At the heart of this it is important that we understand the underlying rationale for emergent theories of embodiment (embodied cognition, embodied interaction), how these intersect with technology development, the extent of research investigating the role and potential roles of 'technology for embodiment' in learning settings, and the potential implications for education.

This review begins by outlining the current theoretical underpinning of embodied cognition and embodied interaction, and the implications for knowledge, creativity and communication in education. We then present an overview of state of the art technologies, including key development trends, and their relationship with interaction and use; followed by a review of interaction and learning based research around these technologies, focusing on technologies embedded in physical learning spaces; virtual environments including gaming; and mixed reality. The discussion draws on this work to both theoretically and practically explore the potential impact of current trends and developments on shaping the future for education, highlighting the key opportunities, challenges and issues that emerge.

2. Embodiment

2.1 Embodied Cognition

The emergence of mobile and ubiquitous technologies has led to increased interest in embodied cognition, and the grounding of ubiquitous technology use in concepts of embodiment. Recent changes in thinking across a number of disciplines emphasise the role of embodiment in cognition. In cognitive science there is a shift from viewing the mind as separate from the body – where cognition is described in terms of abstract mental processes, with an emphasis on symbolic reasoning and internal representation, to one where the mind is intricately connected to sensori-motor experience, with greater emphasis placed on interaction with the environment and real-world thinking (Anderson, 2005; Smith and Gasser, 2005). Work in artificial intelligence has moved from modelling intelligent systems as agent-independent representations of the world to embodied agents evolving through interaction with the environment (e.g. Almeida e Costa and Rocha, 2005). In philosophy the move is away from Cartesian ideas where reason is considered separate from the body, to cognitive functioning being an inter-dependent relationship between mind, body and the environment, where the mind is extended into the external world (Clark and Chalmers, 1998). In psychology there is a shift in focus from the cognition of the individual to a situated, socio-cultural approach to cognition, together with an understanding of the role of sensori-motor interaction in cognitive development and cognitive functioning. Furthermore, recent work in neuroscience provides supporting evidence for such links between sensori-motor and cognitive functioning.

The bases for current thinking on embodied cognition fall into two broad categories (Garbarini et al., 2001): *(i)* the grounding of cognitive processes in neuro-anatomical and biological processes; and *(ii)* the derivation of cognitive processes from sensori-motor (or physical) experience, which is embedded in the psychological and cultural context (Varela et al., 1991). Neuroscientific research shows evidence for direct links between action and perception at the neural level (e.g., Gallese 2000; Kohler et al., 2002 cited Garbarini, 2001). The discovery of mirror and canonical neurons provide evidence for the direct perceptual coupling between object shape and object function, and neural system activation shows a "relationship between *control* of action and *representation* of action" (Gabarini and Adenzato, 2004 p.103). This suggests that representation is closely linked to action, and is constructed through dynamic interaction with the environment. It also changes traditional conceptions of symbolic representation, tying it more closely to physical experience with the world.

Evidence for grounding cognition in sensori-motor experience is more extensive. Principally, our multi-modal sensory systems (Smith and Gasser, 2005) provide an *interrelated* experience of vision, hearing, touch, and action (Titzer, Thelen, and Smith, 2003, cited Smith and Gasser, 2005), which contribute to our understanding and perception of the world. A number of themes about the sensori-motor experience and cognition relationship are outlined:

- Action-perception relationship

This relationship emerges from Gibson's (1977) theory of affordance - the way we perceive the world or objects i.e. shape, size and spatial relations will afford or guide particular kinds of action. Recent experimental studies suggest that perception and action are intricately linked, e.g. participants respond more quickly to visual tasks when accompanied by cues that relate to action (Smith and Gasser, 2005). Furthermore, representation of self in space rather than location per se, is shown to be important in understanding the interplay between perceptual and motor activity (Markman and Brendl, 2005), suggesting that the role of embodiment is more complex than simply a relationship between perceptual and motor functioning.

At the same time action or engagement with the world forms the basis for our understanding of the world (Dourish, 2001). This is exemplified through links between children's understanding of object permanence and the developmental stage of their loco-motor ability (Smith and Gasser, 2005). Action also forms the basis for learning the ability to self-generate goals and strategies for problem solving. When learning to reach for an object infants adopted different strategies depending on their initial type of activity (e.g. flailing arms, placid inactivity) (Corbetta et al., 1996). This facility to explore the physical world through different ways of interacting, are key to developing unique strategies that result in the uniform outcome of a reaching action (Smith and Glasser, 2005).

- Conceptual systems grounded in bodily experience.

Bodily experience and sensori-motor interaction are thought to form the basis for meaning making, e.g. conceptual definition and rationale inference, and physical concrete concepts form metaphorical analogies for abstract ideas (Lakoff and Johnson, 1980). Off-line cognition is also argued to be body-based (Wilson, 2002) i.e. the activity of the mind is grounded in processes that have evolved for interaction with the world. So, even when thinking away from particular contexts our ways of thinking continue to be grounded in physical experience. In relation to recent technology development this conceptual coupling is significant, where emphasis is placed on meaningful coupling between objects, actions and representations (Ishii, 2008).

- Situated cognition

Theories of situated cognition highlight the need to understand and explain cognition in terms of 'situation-appropriate behaviour' (Wilson, 2002; Anderson, 2005). Studies showing how the particular context of a task shapes activity and cognition (e.g. Lave, 1988; Suchman, 1987), re-introduces the importance of situated practice (both social and physical) for cognitive functioning. Cognition also needs to be understood in terms of time-pressured real-time interaction with the world (Wilson, 2002), where cognition is conscious (and therefore time intensive) in unfamiliar situations or tasks, but becomes 'unconscious' in familiar situations. The aim is not necessarily to distinguish situated from non-situated cognition, but to bring to the forefront the importance of context (that encompasses cultural and historical influences) in shaping cognition.

- Environment as external support

The external environment plays a role in supporting cognitive functioning. At a basic level the physical world reduces cognitive processing, i.e. people do not pay attention to what is before their eyes because they don't need to remember what they can see (Smith and Gasser, 2005). At a more abstract level environmental space and gesture support memory and communication (Richardson and Spivey, 2000), and external tools or systems are effectively used to support computation (e.g. Larkin and Simon, 1987; Stenning and Oberlander 1995). Theories of external and distributed cognition emphasise the relationship between internal (mental) and external representations. This sits in contrast to computational models of reasoning which fail to take into account either the interaction or social context of engagement with external representations.

2.2 Embodied interaction

Dourish (2001) coined the term "embodied interaction" to describe "the creation, manipulation and sharing of meaning through engaged interaction with artefacts" - or a merging of tangible interaction with social computing. Tangible computing is where a person interacts with digital information through the physical environment (e.g. Ishii's work at the MIT Media Lab). Social computing, on the other hand, describes the intersection of social behaviour and computational systems and is most often associated with online communities (e.g. Facebook and MySpace). Dourish characterises embodied interaction as grounded in skilled, engaged practice.

However, as technologies move away from desktops and into real world environments or even inside our bodies, increasingly new fields and ultimately forms of embodied interaction are emerging. For example mixed reality games enable players to interact in the real world with online guides, virtual characters moving in real space and unwitting bystanders (Flintham et al., 2003). New theories of embodied interaction pair the physical, digital and social interface with the human sensory system, making it a mix of the virtual and physical, intangible and tangible, reality and fantasy. The rise of graphical virtual spaces such as Second Life (secondlife.com) also provide channels for exploring embodied interaction with or as an *embodied agent* – intelligent agents that interact with the environment through a physical or virtual body within that environment. iRobot's Rooba (http://www.irobot.com) is an example of an embodied agent with a physical body, while an avatar in a game (Isbister, 2006) or in Second Life (Yee et al., 2006) is an example of a virtual embodied agent. Research suggests that embodied intelligent agents have the potential to significantly affect behavior, e.g. Roomba, which is simply a vacuum cleaner, has been shown to affect how families interact with each other and their pets (Forlizzi, 2007).

Embodied interaction in physical or virtual spaces allows us to explore neuro-engineering and notions of *embodied intelligence*. Current research is exploring: how mind-body development shapes our perception, cognition, co-operation and social intelligence; the role of form and material properties in shaping behaviour; and, designing for emergence (Pfeifer & Knoll, 2006). Pfeifer and Knoll's view is that thought is not independent of body and that embodied intelligence has important implications in our understanding of both natural and artificial intelligence (2006).

At the heart of embodied interaction and technology is *communication* - we are less concerned with *what* innovative devices exist as *how* we use them as tools to stimulate thought and action. The inner workings of a mouse are invisible to the non-expert – what is important for the non-expert is what skills are required to use the mouse to perform particular actions. Technologies for embodied interaction then, require an understanding of *skill acquisition*. Perhaps even more important, is how we interpret those skills, as the one performing or reflecting upon the embodied interaction.

2.3 Implications for knowledge, creativity and communication

Embodied cognition and interaction suggest that intelligence lies in the dynamic interaction of brains and the environment, and is centrally dependent on social and cultural worlds (Anderson, 2005). From this overview we can begin to identify some key implications for knowledge creativity and communication in education in the social, technical landscape of today. A key aspect is that sensori-motor experience and interaction with the environment are central to meaning making and conceptual understanding, and provides the basis for learning self-generation of goals and strategies for problem solving therefore. Thus, it not only plays an important role in knowledge construction but also supports other kinds of knowledge such as learning strategy development. Another key aspect is evidence for the role of the external environment and external tools in supporting interaction in social contexts and cognition, especially with current technologies that provide more scope for communication and social interaction, and new ways of recording, collating, storing and re-representing information. The potential of mobile and ubiquitous technologies can also be mapped to other key features of embodiment, e.g. activities that exploit context-related learning, physical interaction and that are grounded in skilled, engaged practice e.g. inquiry-based experiences.

3. Intersection with Technology

Embodied interaction with technologies is realised in many different ways. Table 1 outlines six "hot" topics; where interaction occurs; characteristics of each topic; and the particular focus of the topic. These topics and categories are not mutually exclusive – as technologies become cheaper, faster and more accessible they often slide between the various topics, interactions, characteristics and focus.

Ubiquitous Computing: refers to information processing embedded into everyday artefacts and environments (Weiser, 1991). Ubicomp comprises a wide range of technologies including distributed networking, sensor networks, human-computer interaction and mobile computing (Weiser et al. 1999; Greenfield, 2006). Until recently, ubicomp was seen as the opposite of virtual reality – where interaction is placed inside a virtual world whilst ubicomp places interaction and computation in the 'real world'. However, wireless computing, social networks and mixed-reality continue to redefine our understanding of embodied interaction and ubiquitous computing, and have the potential to push 'traditional' boundaries of where and how to distribute information, offering the capability to change learning environments and outcomes (Dourish, 2001; Rogers et al., 2006).

Proximity Interfaces: Intra-body interfaces rely on proximity, using the human body as a transition medium to allow people to store, display, and exchange information (Zimmerman, 1996). They can act as social networking objects to exchange information about relationships, through common gestures such as a handshake (Kanis et al., 2004) or electronic wallets. This area is rapidly expanding as applications for mobile phones pair social networking information with physical location, e.g. BrightKite (brightkite.com) and Twitter (twitter.com) allow social networking colleagues to see where each other are, meet up with others close by, or list interesting events in close proximity.

Table 1. Table of 'hot' research topics.

Topic	Interaction	Characteristics	Focus
Ubiquitous Interfaces	Off-body	In the world	Embedded computing; distributed exchange
Proximity Interfaces	Intra-body or Near-body	Human body (and object) as transition medium	Store, display and exchange information
Wearable Interfaces	On-body	Removable	Activity recognition and support; body extensions; harvesting human motion
Sensory-specific Interfaces	Body-specific (In hand, ear, nose)	Non-verbal communication	Sensory-dependent (ie. tangible interfaces focus on physicality and touch; auditory on sound; olfactory on smell; visual on sight)
Implantable Interfaces	Inside body	Fixed and implanted	Monitoring of continuous, real-time data (eg. bio-sensing)
Multimodal interfaces	Whole body and Mixed body	Combined sensing and actuation	Dependent on technology type, physicality and sensory appeal.

Wearable Interfaces: are worn on the body, removable, and often considered extensions of the human body. Whilst pioneering applications such as the inverse surveillance system (Mann, 2001) or the early head-mounted displays worn by 'cyborgs' (MIT) seem more like science fiction, recent technology developments have led to mobile phones becoming the most ubiquitous wearable computer and are particularly well suited for mobile multitasking. For example, a wearable headset paired with a mobile phone allows users to drive a car whilst answering incoming phone calls. The fashion industry has taken a keen interest in wearable computing, (e.g. Joanna Berzowska (www.berzowska.com), and Maggie Orth (www.ifmachines.com) and the recent addition of DIY electronic kits such as the LilyPad Arduino board (www.arduino.cc) have introduced embodied interaction, and technology-based interactive fashion into the classroom.

Sensory-specific Interfaces: focus on human senses as input. Olfactory interfaces focus on smell; haptic interfaces on touch; visual interfaces on vision. The least explored area is olfactory interfaces with its realisation only just becoming available in applications such as fire fighting and surgical training. Sensory specific interfaces are often multimodal – haptic and tangible interfaces are often paired with sound and vision.

Implantable Interfaces: Implantable interfaces are fixed inside a body, but because of associated health risks they have long been the domain of medical research and healthcare applications, and often focus on enabling greater accessibility among disabled and challenged patients. However, performance artists are also exploring interaction with implantable interfaces and the ethical and cultural issues and long-term effects associated with extreme surgical intervention e.g. Orlan (www.orlan.net); Stelarc (www.stelarc.va.com.au); Eduardo Kac (www.ekac.org), as well as cybernetics researchers such as Kevin Warwick (www.kevinwarwick.com).

Looking in more detail at developments in the past three years, table 2 outlines the current trends and the biggest movers. Important to note is that all of these fields are motivated by particular agendas, e.g. a software computing company, which sponsors a conference, will tend to select papers, which relate to their technology.

Table 2. Current trends in hot research areas described in Table 1.

Type	Trends
Ubiquitous Interfaces	Interacting in public; privacy; hacktivism; tabletops and touchscreens; location and navigation; smart home; health; sensors and sensor networks; with wearables; gesture, movement and touch; context awareness; social networks; prediction; behavior modification; energy management; craft; tracking in indoor locations; cloud computing; volunteer computing

	Biggest trends: indoor location sensing; context-aware computing, smart home; energy management; volunteering computing
Proximity Interfaces	Social networking; privacy and security; healthcare; contactless interfacing; global tracking; cosmetics convergence versus divergence (applications beyond time and space versus tailoring to individual and immediate need); apparatus for disabling and enabling; toys and games. **Biggest trends:** healthcare; contactless interfacing; social networking; geo-networking
Wearable Interfaces	Health and fitness; design; fashion; virtual coaching; semi-supervised activity; real-time data streams; harvesting human motion **Biggest trends:** health and fitness; fashion
Sensory-specific Interfaces	Games and toys as controllers; tabletop interfaces; voice, sound audio; materials; interactive art; product design and branding; gesture, movement and touch; social networks; mobile phone as tangible device; shape-shifting; large displays; RFID. **Biggest trends:** Approaches to; gesture, movement and touch
Implantable Interfaces	Medical-driven systems; connectors; connecting; electronics; biomedical engineering; microstimulation; nanotechnology; synthetic materials; 3D printing; performance art **Biggest trends:** medical-driven systems; 3D printing; performance art
Multimodal Interfaces	Multi-modality; mobility; mobile presence tools; communal engagement; collaboration; accessibility; green computing; urban computing; intelligent control; social computing; DIY methods; education and learning; performance and live art; video blogging and live streaming. **Biggest trends:** mobile social computing; collaboration; urban computing; DIY methods; education

3.1 Implications for knowledge, creativity and communication

Mobility: In 2008, technology is all about mobility and connectedness. Increasingly technologies are moving from the labs into real-world spaces such as the home, outdoor environments and even nightclubs and festivals (Sheridan et al., 2004). As mobile and smart phones provide more on-demand services and options "cloud computing" will emerge, i.e. people only 'take what they need' whilst being mobile, and leave everything else at work/home/virtual repository. Furthermore, assuming that learning is not restricted to classrooms, increasingly connected mobile devices and similarly connected augmented environments would help bridge gaps between learning contexts, and contribute to the construction of general knowledge.

Multimodality and multi-tasking: Following on from this, people will want to do more things simultaneously. Multimodality and multitask devices provide new means for expressing creativity, in an increasingly fast and demanding society. However, current trends indicate that people want devices and applications that are specific to their immediate needs rather than generalised across devices and applications.

Connectedness and collaboration in the real world: Associated with mobility and constant access to information, the social interaction provided by the increasing connectivity within communities (and the environments) potentially leads to more collaboration, as communication becomes easier and ubiquitous.

Context-based: Ubiquitous, wearable and mobile technologies provide capabilities for bringing new concepts of authenticity to learning environments, by e.g. augmenting real-world contexts, like museums, field trips; augmenting physical role play; and augmenting real-world spaces with virtual overlays of authentic contexts for learning.

Convergence versus divergence: Applications beyond time and space (always on, anywhere) versus tailoring to individual and immediate need (only on now, just here).

Geo-networking and the physical web: Pairing virtual online information from social networking sites with physical location and events in the real world.

4. Technology-based learning research

4.1 Physical space

Biological and psychological aspects of learning have been acknowledged since the 18th century (Jean-Jacques Rousseau) when the use of games, manual works and direct experience, moved learning away from purely memorizing rules and procedures. Hands-on learning has been advocated (Pestalozzi, 1803), implemented in kindergartens (by Froebel in 1837), and largely adopted in schools worldwide (Daltoé and Strelow, 2005), through the use of simple materials and manipulatives like Cuisinaire rods (Fig. 1A) (fractions and proportions), golden blocks (Fig. 1B) (decimal system) amongst others, to stimulate children to express themselves through perceptual-motor activities, and language and play (Colella, 2000).

(A) Cuisinaire rods

(B) Golden blocks

Fig. 1 – traditional manipulatives

In the 80's, computers became popular tools in schools, providing diverse transformative experiences for children's development (Papert, 1980). However, with traditional computers, interaction is screen-based, restricted to mouse and keyboard input devices, thus lacking the advantages of concreteness, physicality, and connection with real-world environments. Recent technological innovations through embedded and ubiquitous computing bring technology-based interaction closer to the so-called "real world" (Weiser et al., 1999), providing new learning experiences that rekindle opportunities for learning through physical activity, engagement with physical objects and real world environments (Eisenberg, 2003; Moher et al., 2008).

4.1.1 Physical interaction

Mobile and sensor based technologies have been used to link physical activity to conceptual ideas, through mapping physical activity to visual or audio representations of abstract concepts, thus encouraging combined physical and cognitive development. Smartstep and Floormat (Scarlatos et al., 1999) used sensor-embedded floor mats to link children's physical movement (e.g. walking up and down the mats) with screen-based visual representations of mathematical concepts (e.g. discrete number line). The mapping of physical action to abstract concepts was thought to "make the activity more meaningful for the child ... partly because the physical objects help children to see – and therefore better understand – abstract concepts in a new way" (Scarlatos, 2006, p.295). More recently configuration of Wii controllers is being used to support applications where physical activity is promoted through digital augmentation. Kahol and Smith (2008) showed that a Wii game (Marble Mania) designed to support movements required for performing surgery, increased surgical dexterity skills. Applications using a Wii remote to measure acceleration of a swinging pendulum, and forces involved in freefall, by transmitting acceleration data in real-time (Vannoni and Straulino, (2007) have also been developed to teach force, velocity and acceleration. More recently, investigations into mapping physical activity with such physics concepts (motion and acceleration) will provide new insights into the value of embodied interaction in learning (Sheridan et al., 2009).

4.1.2 Interacting with physical objects

Similarly tangibles are used to combine the benefits of concrete manipulation with digital technologies to enhance interaction experiences. Tangibles are digitally augmented objects used as input devices to trigger digital effects on a display surface (O'Malley and Fraser, 2004). Tangibles are thought to be beneficial for learning due to the opportunity to exploit their familiarity of interaction; flexible linking to different forms of representation; their affordances for constructive activity; and opportunities for new forms of collaborative interaction.

Several popular (and therefore familiar) toys have been transformed into technological artefacts, e.g. *Bitball* (a transparent sphere that records and transmits information about its own movement (Resnick, 1998)); assembling blocks that involve concepts of behaviour patterns (*Stackables*, *Programmable Beads* (Resnick et al., 1998)); and system dynamics (*FlowBlocks* and *SystemBlocks* (Resnick et al., 1998; Zuckerman et al., 2005)); and blocks that are used as tangible programming elements (Wyeth and Purchase, 2002; Schweikardt and Gross, 2008) to make programming easy and engaging for children.

Other kinds of assembly or constructive kits allow children to build their own, personalized models, stimulating their creativity and imagination. For example, *Topobo* (Raffle et al., 2004) enables children to build creatures out of digitally embedded pieces, which can record and playback physical motion. Research suggests that this process of creating models helps develop a greater understanding about the functioning of things (Klopfer et al., 2002). Children produce knowledge by expressing themselves through the representations they create (Marshall et al., 2003), i.e. the artefact embodies the children's activity and thoughts.

While familiarity may engage children, ambiguous or less familiar representations can promote curiosity and exploration (Rogers et al., 2002). With *Chromarium*, a system to explore colour mixing through physical and digital tools, children experimented and reflected more, with less familiar representations. In this case, children investigated the properties of a model built by someone else (Marshall et al., 2003). Knowledge is produced through exploration (leading to conclusions), rather than expressivity, and therefore there is less space for creativity, suggesting expressive and exploratory systems lend themselves to different contexts.

Tangible environments also lend themselves to collaborative work, as usually a set of interaction objects can be manipulated both by a group and individually. Combining tangibles with tabletops (*Reactable* (Jordà, 2003), *Sensetable* (Patten et al., 2001)) increases collaboration by adding the advantages of concrete manipulation to shareable interfaces that encourage communication, providing face-to-face interaction and multiple, simultaneous users. Recent work suggests how the interactive properties of such shared interfaces supports productive collaborative knowledge building (Pontual Falcao and Price, under review).

4.1.3 Interacting across physical spaces

Technology distributed across physical environments can be used to create collaborative dynamic simulations, which take advantage of whole physical spaces, like classrooms. This typically includes the use of mobile devices, as a way of freely exploring the environments (Klopfer et al., 2002), and embodying meaning-making in activity contexts (Rogers and Price, 2009). Participatory simulations enable students to act as embodied participants (Moher, 2006), as the systems are layered on top of the real world. Instead of watching a screen, students interact with technology distributed across the environment and become part of the simulation, while abstract concepts turn into experience

(Colella, 2000). Such simulations might be seen as large-scale microworlds, as they present scenarios (with context-based information (Klopfer et al., 2002)) mediated by rules and open to knowledge production through investigation and experimentation (Colella, 2000). For example, in the *environmental detectives* system (Klopfer et al., 2002) students investigate ecological issues using portable computers; in a *virus activity* participants explore the spread of disease, by collecting information and communicating through wearable computers (Colella, 2000); in the *Ambient Wood* (Rogers et al., 2002) children discover complex ecology processes whie exploring a digitally enhanced woodland; in *Savannah* (Facer, 2004) children work in teams to learn about animal behaviour and longer term survival, using handheld computers that map the virtual environment to the school playing field; and in *Frequency 1550* mobile phones are used to "transport" children into the past allowing them to explore previous societies (Huizenga et al., 2007). Many of these experiences also engage students in forms of inquiry learning, with the facility to collate diverse sources of data that can be re-represented in the classroom, often using integrated visualisations.

While virtual simulations can overcome and ignore human limitations, the constraints of the human body are naturally taken into account in these systems, through "authentic physicality" (Moher et al., 2008). This represents a shift in the concept of direct interaction, which in the past referred to manipulating agents or parameters through an interface or virtual world. 'Embedded phenomena' is a technology instantiation where scientific phenomena are mapped to classroom physical space (Moher, 2006). Local and partial information about the state of the system is distributed through media across the classroom in a persistent manner, to be monitored and manipulated by students throughout an extended period of time (weeks). Several embedded phenomena systems have been developed and tested in classrooms (*RoomBugs*, *HelioRoom*, *RoomQuake* (Moher, 2006)). The *Wallcology* environment (Moher et al., 2008) expands this framework by enabling distributed collaboration, increasing physicality and expanding the activity sites. The embedded phenomena framework uses ambient media to support embodied interaction, and draws on situated learning and psychology theories that support action as the origin of thought and bodily interactions with the world as the base of cognition (Moher, 2006).

4.2 Virtual space

Embodiment forms a key theme within virtual worlds and computer gaming, where immersion in the activity is considered central for learning (Gee, 2007). Learning content is embedded in the experience, so that meaning making and knowledge construction take place within an appropriate context, rather than a series of facts removed from the activity. Virtual worlds, like physical worlds, are based on the senses, where vision, touch, hearing are supposed to function, and are, therefore, perceived in similar ways to the physical world (Biocca, 1997). In contrast Egoyan (2007) describes the concept of embodiment in virtual worlds as performance rather than as sensation. Through performative experience, changes in our understanding of emotion, actions and behaviours can take place. Important components for interacting in virtual spaces include creativity (constructing identity), communication (the ability to express through an avatar) and performance, but all are bounded by the constraints of the tools available and the design of the game. For example, design may cause release from embodiment through anomalies with the real world e.g. walking through walls. This release from embodiment may, in fact, be a seam around which learning may be mediated – through encouraging different levels of engagement and reflection (Ackerman, 1996).

4.2.1 Creativity

Avatars form the physical instantiation of self to act and interact in a virtual space, which is often made 'real' through objects, spaces, properties and behaviours. Through avatars users create an identity, with physical, social and behavioural attributes of their choice e.g. Second Life, MySpace. On one hand this offers opportunities to explore and experiment with the nature of self and identity, and concepts that are difficult in the physical world (Egoyan, 2007) e.g. relationships, views and behaviours, where interactions with others actually takes place. On the other hand, through avatars people have a tendency to represent their concept of 'me' (although this may change over time) and often express whether they feel 'comfortable' or not in their 'virtual skin' and strive to feel 'right' (Taylor, 2002).

4.2.2 Performance

Although the development of performances in virtual environments such as Second Life are relatively new, they promise exciting possibilities for challenging the way we communicate with each other, perceive our bodies and our relationship to space. Since performance is a reflexive activity, through performance in virtual space we can "reveal ourselves to ourselves" (Turner, 1986: 81). Virtual environments also provide a space for mediating interaction between performers and audience through improvisation and construction of alternative narratives. This not only reveals theoretical possibilities for embodied interaction but also new technical possibilities. New software for creating different identities, for chatting between participants, or even game controllers (such at the Nintendo Wii Remote) challenges how we act with our physical bodies in virtual space.

Performance in general is fundamentally about making things seem real when they are not (Morse, 1998) and much of this theory can be applied to our understanding of embodied interaction in virtual space. For example, emerging avatar performance companies such as Second Front (the first performance art group in Second Life), use performance theory to explore of virtual embodiment, online performance and formation of virtual narrative (slfront.blogspot.com).

Performance, and in particular performance art, has a unique role to play in education. Garoian (1999) claims that performance art is both pedagogical and post-modern. He suggests that a collapsing of the difference between academic and creative work would promote critical thinking in any discipline and that performance art pedagogy represents the "embodied expression of culture as aesthetic experience – that is pedagogy as performance art and performance art as pedagogy" [45].

4.2.3 Communication

Communication is a key component to attaining a sense of presence, which is grounded in both the physical activity of the avatar and social practice. The concept of boundaries, in a physical and social sense, are examples of embodiment and presence, e.g. the sense of someone else (through the avatars) being in 'your' space. Furthermore, "much as in offline life [...] digital bodies are used in a variety of ways – to greet, to play, to signal group affiliation, to convey opinions or feelings, and to create closeness." (Taylor, 2002 p. 41). Virtual avatars can also generate an aura of societies in which there are no boundaries between e.g. cultures, religion. At a different level of interaction, virtual worlds can create a space for inhabiting worlds devoid of these kinds of boundaries, and provide a space where people get to choose how to communicate and how to play out their world in ways that are different from the real world (McIlveny, 1999).

Researchers are seeking to understand factors that trigger high levels of motivation, and activities within 'gaming' settings that might contribute to learning. Prensky (2007) goes beyond this suggesting that the physical structure of brains is different for those growing up in a digital world (cf Luria 1979 - environment and culture affects the way we think; different cultures *think differently*), and that there is a different blend of cognitive skills that is a product of exposure to multiple digital media. However, the need for interactivity, immediate feedback and response, to maintain attention is highlighted, together with the concern that this is coupled with less time and opportunity for reflection (Prensky, 2001). One focus of gaming research, rather than advocating games per se for learning, is to take lessons learned in terms of learning principles that can be found in game culture.

Gee (2007) outlines fifteen features of video games that form the basis for good learning. Some key features that are useful to consider in the context of this review include *(i)* Identity (for real learning the learner needs to make a commitment done through identity in games.) and customisation (the ability for the player to choose roles that suit them) are both concerned with self and preference. This raises issues of whether it is educationally important or not to encourage students to take on unfamiliar roles or to do the things they find harder. *(ii)* Risk taking: (offering the opportunity for positive failure and therefore encouraging risk taking, and which maps well to current thinking about the value of exploratory learning) and well order problems (the need to order problems so that they always build on ones solved earlier, thus avoiding the issue of exploratory learning where creative solutions may be found, but don't lead to good learning about how to solve later problems (see Elman, 1991)) suggest the complexity of integrating good learning practice into education. *(iv)* Challenge and consolidation (games follow a 'cycle of expertise' – i.e. get a set of challenging problems which are solved many times until routinised and then more problems given) suggest similar strategies used in some traditional teaching in school, suggesting evidence of a good strategy worth continuing. *(v)* Performance before competence (offering the facility to perform before you need to be competent) is akin to exploring, discovering, an underlying ethos to a number of learning experiences with mobile and ubiquitous technologies.

4.3 Intersection between physical and virtual space

Mixed reality, also known as 'augmented reality', describes the intersection of the real and virtual – where interaction in the real world with physical objects effects interaction in the virtual world with virtual objects and characters (and visa versa). With the introduction of smaller, cheaper and mobile technologies, mixed reality opens the possibility for new kinds of embodied interaction in educational settings. Mixed reality in teaching environments provides opportunities to explore embodied interaction through self and remote learning. The MiTRLE project is a mixed reality teaching environment, which pairs local students with remote students through a virtual world in a higher education setting. The aim is to foster a sense of community amongst remote students on the basis that avatar representations of teachers and students will help create a sense of shared presence, engendering a sense of community and improving student engagement in online lessons (Gardner et al, 2008).

Mixed reality environments also have real-world implications. Geonetworking merges information from social networking sites with real-world physical locations. Live Geo Social Networking applications such as Twitter merge this information in realtime so that participants can post and search geo coordinates of time critical items. For example, a person can use a mobile phone to post information about an event they are witnessing in real time and all other interested parties in the vicinity can search, see and get directions to the event. These applications could have wide reaching implications for remote and collaborative self-learning in mixed reality settings although, attention needs to be paid to the risks involved in sharing such information.

5. Discussion

Technology-based applications can create new kinds of learning spaces – both physical and virtual, that bring opportunities to exploit the value of embodiment for learning and interaction. Assuming that learning content is embedded in experience and knowledge production should take place in appropriate contexts, immersion in learning activities is also fundamental. Technology interfaces presented in this review can support engagement in directly active and participative ways, for example, through physical activity and experience in authentic contexts; exploration, discovery and experimentation; use of new external tools that can mediate action and thought; collaboration and communication and (including that which occurs through forms of expression); creativity through expression and production; learning activities and situations that provide new catalysts for reflection and discussion around learning domain; and inclusion of students with physical disabilities and /or learning difficulties through multimodality and collaboration. Collaborative and communicative activity changes offering new forms of interaction and activity, including: sharing of information e.g. embedded phenomena; transferring of data through physical proximity e.g. participatory simulations; and expressions of knowledge or creations through production, e.g. virtual worlds, MySpace, re-representations of collated data e.g. Ambient Wood/ Savannah; and expression or communication through performance activities, e.g. avatar performance art groups like Second Front. In addition, different relationships between student and teacher (e.g. as facilitator /guide) can be promoted, which maps to the emerging prominence of independent learning in the current (science) curriculum (Lombardi, 2007). At the same time this raises issues about students' competence at taking on a more independent self-generated activity or role that this demands, and teachers' ability or familiarity with facilitating learning.

However, such opportunities also raise a number of issues and challenges for education. Here we provide two scenarios derived from ideas raised earlier to identify and discuss the key opportunities, challenges, risks and demands that emerge within the context of embodiment, technology and education. With each scenario we identify some specifically related opportunities and issues, and then discuss the general risks, challenges and demands that such scenarios might bring.

5.1 Scenario 1: Embedded experiences

Opportunities: Features of mobility and sensor embedding technologies provide new opportunities to re-think space, place and classroom organisation. Applications like the 'embedded phenomena' engage large groups of children in science learning in radically different ways within a classroom setting. The 'persistent' concept in this model of augmented learning, where the phenomena run over weeks or months, and where the activity is related to but asynchronous with the regular flow of instruction in the classroom, illustrates new openings for rethinking models of instruction and classroom practice (Price, 2007). In 'embedded' experiences, students are repeatedly exposed to different pieces of information distributed across the physical space of the classroom, and given opportunities for role-play providing them with experiences from different perspectives and the means to build a collective and comprehensive understanding. Research has illustrated how this might work in science learning, but we could also imagine structuring history and geography learning in similar ways. Imagine learning a time period in history or geographical changes (climate or landscape changes) where events over time are experienced within the classroom across a several week period. In history this might follow a series of pertinent events from the start to the end of a world war. In geography this might illustrate the formation of the ice age with speeded up time events and examples of the changes taking place to the land and the people living there. Students could be alerted to particular events taking place at appropriate points in time and access video showing events; take environmental measurements that demonstrate the climate change; or even opportunities to take part in political debates at pertinent times as historical events unfold. Such interaction promotes extended exposure to a topic, enabling reflection over time, but furthermore provides new opportunities for students to experience and understand causal events over time.

Challenges/ demands: Integrating learning activity that is distributed across extended periods of time, and across the classroom space brings challenges and demands for restructuring of classroom practice, particularly use of space, time management, dealing with interruption, and organisation of student activities. The requirement for students to work in groups independently from the teacher, taking more control of organizing their activities to reach their goals, poses challenges for changes in teaching style and student expectations about learning.

Risks: Evidence for the potential of this scenario exists in scientific domains, but not other subject areas, although geography, history or even language learning could be supported in new ways using this design of embedded technology experiences.

5.2 Scenario 2: Shareable interfaces

Boundaries between physical and social spaces, and between different kinds of knowledge or learning contexts (informal/ formal) are also changing, offering opportunities for ways to integrate everyday experience and interaction for learning. Mobile technologies offer opportunities to extend learning beyond the classroom, bridging the gap between home and school, and between field-work and classroom. Mobile phones and other multi-functional handheld or personal devices can be carried around, enable access to, recording of and communication of various forms of information and data, including photos, video, scientific measurements, survey records. Such tasks are freed from the classroom and can become living experiences, enabling learning to be more embedded in students own experiences and real-world topics of relevance. Both horizontal and vertical surfaces can be used in the classroom to display data uploaded from the different sources, which can then be used for sharing, explanation and discussion in classroom settings. Flexible use of large displays could exploit both small group and large class interaction. For example, table-tops are particularly suitable for small group interaction, but can also be combined with large displays to provide a forum for sharing student information with a broader audience. Such table-top interaction also provides opportunities for student expression, explanation and demonstration.

Challenges: Particular challenges in this scenario include: teacher development in managing fluid and uncontrolled learning outcomes, and their ability to manage increased instances of small group interaction; managing resources e.g. number of artefacts available might limit number of participants (what will the rest of the class be doing?), physical location of the technology hardware within the school: in a specific room (need for pre-planning and booking resources and possible "dispute for resources" among teachers) or within the classroom (having technology at hand to be used whenever needed, as support tools); managing firewall issues with internet access, including security and privacy issues; practical management of integrating personal devices/ multiple devices with school-based technologies.

Risks: Insufficient provision of technology resources might limit the number of participants (how will teacher manage this?). In addition, the use of personal devices (rather than school distributed resources) might create unequal opportunities among children due to socio-economic issues.

5.3 General challenges, demands and risks across scenarios

Key challenges and demands

While offering new ways of learning, technology also raises challenges for *teacher education, training and professional development*, not only in terms of practically implementing changes, but knowing what kind of changes are needed. This is essential to avoid concerns that technology is often not integrated into education/ teaching in a way that is likely to be successful (Selwyn, 2007). Changes in learning space and time, demands creatively developing the curriculum to accommodate learning activities that support different learning processes (rather than specifically targeting factual learning, which should occur through effective activities and teaching practice), and to support re-structuring of the school day (to promote new forms of classroom interaction). This would promote new use with technology rather than mapping to current teaching practice. Teachers themselves need to become more familiar and proficient with developing and changing technologies, and the potential implications for their teaching practice.

A key challenge is how best to *design learning experiences* within the context of current knowledge on technology, embodiment and learning. Learning experiences described here were designed and developed through large multi-disciplinary groups. For educational contexts technology must be developed together with pedagogical aims guided by the teacher's planning and scaffolding (Moher et al., 2008). This raises challenges for the development of technology-based learning experiences which requires multiple expertise, and demands not only the involvement of teachers or school-based technicians in the design process, but also having the personnel with skills to modify, apply and orchestrate learning experiences for different groups of students or subject domains. This requires competent programmers to develop the different activities, and skilled technicians in school to run and maintain the technology experiences.

In terms of students learning, flexible use and linking of information through digital communication and augmentation, requires careful design and management. Increased combinations of representations require learners to attend to and integrate diverse pieces of information from different data sources. The degree to which novices (students) are able to focus on and extract appropriate information impacts on their abilities to engage in effective knowledge acquisition activities (deGroot, 1965; Glaser, 1992), suggesting the need to understand how experiences can be designed to effectively provoke learning (Price et al., 2008). A further challenge is moving beyond the 'experience' itself, and mapping this to other forms of knowledge. Consideration needs to be given to the kind of knowledge that technology-mediated experiences effectively promote (e.g.

procedural, factual, creative, or different forms of skill development), and how to integrate it with other forms of knowledge or learning activities. At a more general level, this requires re-thinking what constitutes 'learning' within 'education' together with specifying desired outcomes or end goals.

Broadening the use of communication technologies beyond the classroom raises serious challenges about how to enable *safe, accessible and innovative e-Learning strategies*. Firewalls serve an important role in protecting children from inappropriate digital content, but they often prevent teachers and pupils from effectively using e-Learning tools and technologies in the classroom. Heavy restrictions placed on the use of everyday communication tools, such as email (e.g. file size, file type) or more advanced tools such as Skype and YouTube filter external Internet content, but affect the quality and type of information that teachers can present in the classroom. However, communication technologies can disrupt the classroom and Internet misuse is widespread. For example, many bright pupils are able to by-pass government approved firewalls to access X-rated and violent websites and statistics in the UK suggest that one quarter of pupils at every school is avoiding firewalls.

Key risks

Radical changes in technology use and implementation in education demands significant financial investment in technology hardware, software and skilled personnel. A key risk is that insufficient financial and training/ development opportunities will reduce the likelihood of successful educational transformation. If technology is to be embedded in useful ways, then teachers need to have more competence and familiarity with working with different technologies. Furthermore, the need to attract appropriately skilled designers and developers, and educationally based technicians is of paramount importance to effectively embed ubiquitous technologies into educational practice.

Ubiquitous technologies provide opportunities to re-think (some) learning activities to exploit the everyday interactions young people have through their own technology devices, promoting motivation through (for them) familiar forms of interaction (e.g. Gee, 1999; Prensky, 2001). However, a key risk here is focusing on engagement to the detriment of learning. It is important to note that despite bringing about positive effects, physical action and entertainment do not, on their own, guarantee learning benefits. This again highlights the need to re-consider what 'learning' entails.

6. Conclusion

Taking into account evidence and theories arising from embodied cognition and interaction, developments in computing technologies, and evidence from research, the future for education is set to change. Paying attention to and integrating up-to-date technology into education is of paramount importance, as it inevitably forms a central part of everyday life, but much work is yet to be done to establish effective ways of using these technologies to promote learning – both in formal and informal contexts. Of emerging significance are the potential changes in learning activity and learning process that are precipitated through technologies. Ubiquitous learning experiences demand different kinds of endeavours and activity than (some) traditional learning activities. We can see how ubiquitous learning environments (both physical and virtual) can provide 'spaces' within which learners can explore, discover, experience concepts/ideas, and which can serve as a discussion forum e.g. getting students to think about different issues and different boundaries. Inherent in this process is the re-thinking of what education means for developing learners; what are the central components of learning and the kinds of skills that learners will need to acquire to engage fruitfully in adult society and life. This requires not only understanding the underlying drivers for learning, but also the implications for teachers (their role, practice and training) and the development of curriculum and educational establishments. Research effort and evidence is needed exploring effective ways for teachers to know *how* to use and adopt technologies.

7. References

Ackermann, E. (1996) Perspective-taking and object construction: two keys to learning. in Kafai, Y. and Resnick, M. eds. *Constructionism in practice: designing, thinking, and learning in a digital world*, Lawrence Erlbaum, Mahwah, NJ, 25-35.

Almeida e Costa, F. and Rocha, Luis M. (2005) Embodied and Situated Cognition, *Artificial Life,* vol 11 (1,2) MIT Press

Anderson, M. (2005) Embodied Cognition: A field guide. *Artificial Intelligence*, 149, 91-130.

Biocca, F. (1997) The Cyborg's Dilemma: Progressive Embodiment in Virtual Environments *Journal of Computer-Mediated Communication*. Volume 3, No. 2 September, 1997

Clark, A. and Chalmers, D. (1998) The extended mind. *Analysis* 58:10-23. Reprinted in (ed) P. Grim, *The Philosopher's Annual*, vol XXI, 1998

Colella, V. (2000) Participatory Simulations: Building Collaborative Understanding Through Immersive Dynamic Modeling. *The Journal of the Learning Sciences,* 9 (4), 471 – 500, Lawrence Erlbaum Associates.

Corbetta, D., & Thelen, E. (1996). The developmental origins of bimanual coordination. *Journal of Experimental Psychology: Human Perception and Performance*, 22, 502–522.

deGroot, A. 1965. *Thought and choice in chess*. The Hague. Mouton.

Dourish, P. (2001) *Where The Action Is: The Foundations of Embodied Interaction*. MIT Press.

Egoyan, M. (2007) Virtual Embodiment embodied research group. http://embodiedresearch.blogspot.com/2007/12/virtual-embodiment.html *last retrieved September 2008*

Eisenberg, M. (2003). Mindstuff: Educational Technology beyond the computer. *Convergence*, 9(2).

Facer, K. (2004) Savannah: a Futurelab prototype research report. *Futurelab report*.

Flintham, M., Benford, S., Anastasi,R., Hemmings, T., Crabtree, A., Greenhalgh, C., Tandavanitj, N., Adams, M. and Row-Farr, J. (2003) Where on-line meets on the streets: experiences with mobile mixed reality games. *Proceedings of the SIGCHI conference on Human factors in computing systems,* Ft. Lauderdale, Florida, USA, April 2003, ACM Press, p. 569 – 576.

Forlizzi, J. (2007) How robotic products become social products: an ethnographic study of cleaning in the home. *Proceedings of the ACM/IEEE international conference on Human-robot interaction*, 129 – 136, 2007.

Gabarini, F. and Adenzato, M. (2004) At the root of embodied cognition: Cognitive science meets neurophysiology. *Brain and Cognition* 56, 100-106.

Gardner, M., Scott, J. and Horan, B. (2008) *EDUCAUSE Review,* vol. 43, no. 5 (September/October)

Garoian, C. R. (1999) *Performing Pedagogy: Towards an Art of Politics.* Albany: State University of New York Press, 248 pp. 33

Gee, P. (2007) *Good video games and good learning: Collected essays on video games*. Peter Lang Publishers

Gibson, J. J. The Theory of Affordances. (1977) In *Perceiving, Acting, and Knowing*, Eds. Robert Shaw and John Bransford.

Glaser, R. (1992) Expert knowledge and processes of thinking. In (ed.) D.F. Halpern, *Enhancing Thinking Skills in the Sciences and Mathematics.* pp. 63-75 Hillsdale, NJ: Erlbaum.

Greenfield, A. (2006). *Everyware: the dawning age of ubiquitous computing*. New Riders, p 11-12.

Huizenga, J., Admiraal, W., Akkerman, S., Dam, G. T. (2007) Learning History by Playing a Mobile City Game. In A. Popova (Ed.), *Proceedings of the 3rd Technology-enhanced Learning Enlargement Workshop,* September 28th. 2007 Sofia Bulgaria (pp. 31-41). Sofia : St. Kliment Ohridski University Press.

Isbister, K. (2006) *Better Game Characters by Design: A Psychological Approach, The Morgan Kaufmann Series in Interactive 3D Technology*. Morgan Kaufmann Publishers Inc. San Francisco CA, USA.

Ichida, H., Itoh, Y., Kitamura, Y., and Kishino, F. (2004) ActiveCube and its 3D applications. In *IEEE Virtual Reality Conference (VR'04)*, Chicago, USA.

Ishii, H. (2008) The tangible user interface and its evolution. *Communications of the ACM*, June 2008, Vol. 51 N.6

Jordà, S. (2003) Sonigraphical Instruments: From FMOL to the reacTable. *Proceedings of the 3rd Conference on New Interfaces for Musical Expression (NIME 03),* Montreal (Canada)

Kahol, K. and Smith, M. (2008) Surgeons on Wii: Applying Nintendo Wii to Improve Surgical Skill. *The 16TH Annual Medicine Meets Virtual Reality Conference* California

Kanis, M., Winters, N., Agamanolis, S., Cullinan, C. and Gavin, A. (2004) iband: a wearable device for handshake-augmented interpersonal information exchange. demo, September 2004.

Klopfer, E., Squire, K., and Jenkins, H. (2002) Environmental Detectives: PDAs as a Window into a Virtual Simulated World. In: *Proceedings of the IEEE International Workshop on Wireless and Mobile Technologies in Education, WMTE 2002*: 95-98, Växjö, Sweden.

Lakoff, G. and Johnson, M. (1980*). Metaphors we live by*. Chicago: University of Chicago Press.

Lave, J. (1988) *Cognition in practice: Mind, Mathematics and Culture in everyday life*. New York: Cambridge University Press.

Lombardi, M. (2007). Authentic learning for the 21st century: An overview, *Educause learning initiative,* Diana G. Oblinger (Ed.). Last retrieved on December 5, 2008 http://net.educause.edu/ir/library/pdf/ELI3009.pdf

Luria, A. (1979) *The Making of Mind A Personal Account of Soviet Psychology.* Michael Cole and Sheila Cole, eds. Harvard University Press.

Mann, S. (2001) *Cyborg: Digital Destiny and Human Possibility in the Age of the Wearable Computer* Randomhouse Doubleday 2001.

Markman, A. and Brendl, M. (2005) Constraining Theories of Embodied Cognition. *Psychological Science*. Vol. 16, No. 1 6-10. APS.

Marshall, P., Price, S., and Rogers, Y. (2003) Conceptualising tangibles to support learning. In *Proceedings of Interaction Design and Children (IDC'03),* Preston, UK. ACM Press.

McIlvenny, P. (1999) Avatars R Us? Discourses of Community and Embodiment in Intercultural Cyberspace. *Intercultural Communication* August, issue 1

Moher, T. (2006) Embedded Phenomena: Supporting Science Learning with Classroom-sized Distributed Simulations. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'06)*, Montreal, Canada, ACM Press.

Moher, T., Uphoff, B., Bhatt, D., Silva, B. L., Malcolm, P. (2008) Wallcology: Designing Interaction Affordances for Learner Engagement in Authentic Science Inquiry. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'08)*, Florence, Italy.

O'Malley, C. and Fraser, D. S. (2004) Literature review in learning with tangible technologies. *Technical Report 12*, NESTA Futurelab.

Papert, S. (1980) *Mindstorms: Children, computers and powerful ideas*. NY, Basic Books.

Patten, J., Ishii, H., Hines, J., and Pangarp, G. (2001) Sensetable: a wireless object tracking platform for tangible user interfaces. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'01)*, Seattle, USA. ACM Press.

Pestalozzi, H. (1803) *ABC der Anschaunng, oder Anschaunngs-Lehre der Massverhaltnisse*. J.G. Cotta, Tubingen, Germany.

Pfeifer, R. and Knoll, A. (2006) Intelligent and Cognitive Systems. *Beyond the Horizon*, v3.1. January 31.

Piaget, J. (1972) *The Principles of Genetic Epistemology*. Basic Books, New York, USA.

Price, S., Sheridan, J., Pontual Falcao, T. and Roussos, G. (in press) Towards a framework for investigating tangible environments for learning. To appear in *International Journal of Arts and Technology:* Special Issue on Tangible and Embedded Computing

Price, S. (2007) Ubiquitous computing: Digital Augmentation and Learning. In (ed.) Pachler N. *Mobile Learning: Towards a Research Agenda*. Occasional Papers in Work-based Learning 1 WLE Centre, London

Raffle, H., Parkes, A., and Ishii, H. (2004) Topobo: A constructive assembly system with kinetic memory. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'04),* Vienna, Austria.

Resnick, M. (1998). Technologies for lifelong kindergarten. *Educational Technology Research and Development*, 46(41).

Resnick, M., Maryin, F., Berg, R., Boovoy, R., Colella, V., Kramer, K., Silverman, B. (1998) Digital manipulatives: new toys to think with. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'98)*, pages 281–287, Los Angeles, USA.

Richardson, D. and Spivey, M. (2000). Representation, space, and Hollywood Squares: Looking at things that aren't there anymore. *Cognition*, 76, 269 – 295.

Rogers, Y. (2006) Moving on from Weiser's vision of of calm computing: engaging UbiComp experiences. In: P. Dourish and A. Friday (Eds.) *Ubicomp 2006 Proceedings*, LNCS 4206, pp. 404-421, Springer-Verlag

Rogers, Y. and Price, S. (2009) How Can Mobile Technologies Change The Way Children Learn? To appear in (ed.) Druin, A. *Mobile Technology for Children: Designing for Interaction and Learning,* Elsevier

Rogers, Y., Price, S., Harris, E., Phelps, T., Underwood, M., Wilde, D. and Smith, H. (2002) Learning through digitally-augmented learning experiences: Reflections on the Ambient Wood project. (*Equator technical report*).

Scarlatos, L. L., Dushkina, Y., and Landy, S. (1999) TICLE: A tangible interface for collaborative learning environments. In *Extended Abstracts of the SIGCHI Conference on Human Factors in Computing Systems (CHI'99),* pages 260–261, Pittsburgh, USA.

Scarlatos, L. L. (2006). Tangible Math. *International Journal of Interactive Technology and Smart Education*, Special Issue on Computer Game-Based Learning, volume 3, issue 4, 293-309.

Schweikardt, E. and Gross, M. (2008) The robot is the program: Interacting with roBlocks. In *Proceedings of the Second International Conference on Tangible and Embedded Interaction, TEI'08*. Bonn, Germany.

Sheridan, J. G., Price, S. and Pontual Falcao, T. (2009) Wii Remotes asTangible Exertion Interfaces for Exploring Action-Representation Relationships. To appear in *Whole Body Interaction Workshop SIGCHI Conference on Human Factors in Computing Systems (CHI 2009)* Boston, MA, USA.

Sheridan, J.G., Dix, A., Lock, S. and Bayliss, A. (2004) Understanding Interaction in Ubiquitous Guerrilla Performances in Playful Arenas. S. In Fincher, P. Markopolous, D. Moore, & R. Ruddle (Eds.): *People and Computers XVIII-Design for Life: 18th British HCI Group Annual Conference,* pp. 3-17, Springer-Verlag, 6-10 September, Leeds, UK. ISBN: 1-85233-900-4

Smith, L. and Gasser, M. (2005) The Development of Embodied Cognition: Six Lessons from Babies. *Artificial Life* 11: 13–29

Suchman, L. (1987). *Plans and Situated Actions: The Problem of Human-Machine Communication*. Cambridge, U.K. Cambridge University Press.

Taylor, T. (2002) Living Digitally: Embodiment in Virtual Worlds. In R. Schroeder (Ed.) *The Social Life of Avatars:* Presence and Interaction in Shared Virtual Environments. London: Springer-Verlag.

Vannoni, M. and Straulino, S. (2007) Low-cost accelerometers for physics experiments *European Journal of Physics,* 28, 781-787.

Varela, F., Thompson, E., and Rosch, E. (1991) *The embodied mind. Cognitive science and human experience.* Boston: MIT Press.

Vygotsky, L. S. (1978). *Mind and Society*. Harvard University Press, Cambridge, USA.

Weiser, M., Gold, R., and Brown, J. (1999) The origins of ubiquitous computing research at PARC in the late 1980s. *IBM Systems Journal*, 38(4).

Weiser, M. (1991) The Computer for the Twenty-First Century," *Scientific American,* pp. 94-10, September.

Wilson, M. (2002) Six views of embodied cognition. *Psychonomic Bulletin and Review* 9 (4), 625-636

Wyeth, P. and Purchase, H. C. (2002) Tangible programming elements for young children. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'02),* pages 774–775, Minneapolis, USA.

Yee, N. (2006) The Labor of Fun: How Video Games Blur the Boundaries of Work and Play. *Games and Culture* 1: 68-71

.Zimmerman, T.G. (1996) Personal area networks: Near-field intrabody communication. *IBM Systems Journal*, 35(3-4):609–17.

Zuckerman, O., Saeed, A., and Resnick, M. (2005) Extending tangible interfaces for Education: digital Montessori-inspired manipulatives. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'05)*, pages 859–868, Portland, USA. ACM Press.