Touching the virtual, touching the real: iPads and enabling literacy for students experiencing disability

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ABSTRACT

In this paper we discuss the potential of iPads for supporting literacy learning in special education, with a focus on how the gestural and sensory experience of touch can enable young learners with moderate to complex physical and/or cognitive disability to engage in fun, independent and inclusive classroom-based literacy activities. We report on a case study where we observed the literacy learning opportunities offered by the touch screen interface provided by iPads for a diverse group of students aged 3 to 19 years in a special school in the English Midlands. We also made field notes and sought teachers' and students' views about the potentials and challenges of using iPads in the classroom. We begin by outlining our interdisciplinary theorisation of touch, and conceptualisations of its role in learning. Applying these concepts to the data, we discuss the affordances and constraints of iPad devices in terms of mobility, flexibility and sensory experience. We then illustrate how the sensory and kinaesthetic experience of human touch often enhanced the students' motivation, control and independence when engaged in literacy endeavour with iPads, and led to high levels of achievement and creative opportunities for their self-expression.

Introduction

The role of touch in learning is complex, with multiple facets, which we approach with insights from diverse disciplines. We draw primarily on social semiosis and multimodality to define our use of the terms 'touch', 'gesture' and 'pointing', whilst also considering neuroscience and psychological references to these phenomena. Central to this paper are the notions of real, vicarious, and virtual touch, where 'real' touch implies physical contact between a person and another person or object, 'vicarious' touch implies observing other peoples' enactment of touch, and 'virtual' touch implies touching virtual objects on a touch-sensitive digital screen. We adopt Merleau-Ponty's (1964; 1968) phenomenological conception of embodied knowledge to clarify our ontological position regarding the intimate relationships between body, mind and the sensory, and kinaesthetic experience of touch. We also refer to literature from the field of education in our data interpretation, particularly in relation to the nature of literacy in the contemporary world, and the use of touch-screen devices for classroom-based communication and literacy.

Touch and haptics

'Haptics' is commonly used in experimental psychology and neuroscience to refer to the somatosensory system, which enables us to experience the environment through active exploration, typically with our hands, such as when palpating an object to gauge its shape

and material properties. This perceptual system is mediated by cutaneous sensations of the skin combined with kinesthesis, involving position and movement (Lederman & Klatzky, 2009), and is 'critical for normal human functioning at many different levels, from controlling the body to perceiving the environment, as well as learning about and interacting with it' (Robles de la Torre, 2006, p. 29). Technological advances have led to the development of tactile digital interfaces, which tap into this somatosensory system – the iPad being amongst the most widely adopted at the current time. To understand the potential of these devices for learning, we draw on recent neuroscience research and on established ecological approaches to perceptual learning, where touch is viewed as a sensory mode within a larger perceptual system (Gibson & Pick, 2000), and where perception entails a reciprocal relationship between people and their environments. Central to this reciprocity is Gibson's (1986) concept of affordance: that objects in the environment afford certain actions and people respond to those affordances as they deem appropriate.

Kress (e.g. 1993; 2010) has adapted Gibson's notion of affordance in his approach to multimodality, which extends Halliday's (1978) social semiotic theory beyond language to the role of visual, aural, and embodied modes in meaning-making, and the multisensory nature of diverse modes (Kress, 2010; Simpson, Walsh & Rowsell, 2013). Here, the term affordance refers more specifically to what it is possible to express effectively with different modes of communication in different contexts (such as representing complex ideas through diagrams in learning/teaching), and what might be less effective (such as expressing empathy through words in a noisy social setting). From this perspective, the term 'affordance' is not merely a matter of perception, but refers to the materially, culturally, socially and historically developed ways in which meaning is made with particular semiotic resources. Common across these different disciplinary approaches is the conceptualisation of touch as a multi-level sensory resource within overlapping somaesthetic and communication systems which people draw on selectively to make meaning in specific situations. We focus on the three principal resources of touch, gesture and pointing, and in the next section, we clarify the distinctions we make between these terms.

Touch, gesture and pointing

A distinguishable characteristic of touch is that it can render human experience communicative, sensory and embodied. We theorise about these characteristics by drawing on Merleau-Ponty's Phenomenology of Perception, which is premised on the 'incarnate relationship' between self and the world of others (1982, p. 33). All human experiences intertwine in the corporeality of the body and the objects humans interact with, giving rise to embodied lived experiences where the materiality of the physical world becomes entangled with the minds and bodies of individuals. Sensory experience is always double, as the human body has the capacity of being both sensate and sensible, and for touch, there is a 'crisscrossing within it of the touching and the tangible' (Merleau-Ponty, 1968, p. 133). So, for example, when touching a physical object, a person experiences touch only on one level, while touching one's own body affords the double experience of touching and being touched. This double experience of tactile and tangible corresponds to Merleau-Ponty's premise that rather than being separate entities, there is an intricate and entangled relationship between body and mind, which extends to the objects with which a person interacts:

> In the action of the hand which is raised toward an object is contained a reference to the object, not as an object represented, but as that highly specific thing toward which we project ourselves … to move one's body is to aim at things through it; it is to allow oneself to respond to their call. (Merleau-Ponty, 1962, p. 139)

Taking sensory experience beyond the realm of the tactile and the tangible, recent work in neuroscience suggests that a neurophysiological mechanism in the human brain – the mirror-neuron mechanism – plays a fundamental role in the human capacity to interpret the actions and sensory experiences of others (Rizzolatti & Craighero, 2004):

> The essence of this 'mirror' mechanism is as follows: whenever individuals observe an action being done by someone else, a set of neurons that code for that action is activated in the observers' motor system. Since the observers are aware of the outcome of their motor acts, they also understand what the other individual is doing without the need for intermediate cognitive mediation. (Rizzolatti, Fabbri-Destro & Cattaneo, 2009, p. 24)

There is therefore not only an intricate and entangled relationship between body and mind, which extends to the objects with which a person interacts (Merleau-Ponty, 1962), but current neuroscience research suggests that the neurological mirror mechanism unifies the perception and execution of one's own and others' action. This in turn signals the complexity of the relation between real and vicarious touch (whether observed in real or recorded time, such as in a film), and suggests a further layering of haptic experience through virtual touch when using touch-screen interfaces.

Touch often, although not always, involves gesture,

which plays a unique and integral role in communication and development. Vygotsky (1978) argued that gestures lay the groundwork for symbol use in writing: 'The gesture is the initial visual sign that contains the child's future writing as an acorn contains a future oak. Gestures, it has been correctly said, are writing in the air, and written signs frequently are simply gestures that have been fixed' (Vygotsky, 1978, p. 107). Kendon (2004) likens gestures to utterances expressed as visible action, and Trevarthen (1995) observed how young infants' movements during early 'protoconversations' have a meaningful communicative function and are central to social development within cooperative and emotionally rich relationships with parents and carers.

Research into the use of gesture by children with hearing impairment has evidenced that children's self-created gestures follow design principles usually associated with language (Goldin-Meadows, 2003). Building on these insights, we conceptualise gesture as a deliberate act of communication (including when directed towards oneself), where gestural meanings can be shared and understood by others. Pointing is a particular form of deictic gesturing used to draw the attention of the addressee(s) to a near, distant or even absent object, where a directing to (or pointing) vector is created, often by index-finger pointing, but also by, for example, an arm movement or gaze direction (eye pointing).

Gesture, particularly the deictic gesture of pointing, is therefore usually intentional, whereas touch can be either intentional or incidental. Touch may or may not be deictic, but includes somaesthesis (cutaneous and kinaesthetic experience) resulting from contact between humans or between a human and an object, such as stroking, holding, or squeezing (Hertenstein, 2002). To gain more insight into the pragmatic potential of real, vicarious and virtual touch for learning, in the next section we consider empirical evidence on the role of touch in literacy learning. First, we clarify how literacy is conceptualised within this paper.

Literacy, touch and learning

We adopt a sociocultural approach to literacy as embedded in social practice (Street, 1995). Rather than seeing literacy development as the context-free acquisition of a set of encoding and decoding skills (Gough & Tunmer, 1986), we recognise the complex processes at play during the reading or production of texts, where the writer/reader is required to understand and engage in the particular literacy practices of a social community. These practices change over time, and in the current era are often mediated by screen-based technologies, where the term 'text' covers a range of modes and media (Barton & Lee, 2013).

Aspects of touch feature in many studies of literacy learning, yet to date their contribution has remained comparatively under-theorised. Touch and gesture are not merely supplementary to speech but are finely integrated with it. For example, Messer (1978) found that with young children aged up to 24 months, gaze and touch integrate the mother's and the infant's interest in features of the environment, and through touch, children can identify the topic of social interaction and speech (Tomasello & Farrar, 1986; Hani, Gonzalezbarrero & Aparna, 2013). Established research in classrooms has shown how teachers often touch objects to draw attention to the locus of learning (e.g. Flewitt, Nind & Payler, 2009; Mavers, 2009), and how early readers trace words with their finger as they read aloud (e.g. Manguel, 1996). In public spaces such as museums and libraries, children are encouraged through displays and interactive resources to explore literacy artefacts by touching them, on the basis that physical contact promotes children's participation and engagement with objects on display (Nichols, 2011).

There is little doubt that touch engages learners' enjoyment of using touch and bodily contact to explore objects and can be related to perceptual learning and their wish to experience new things in a multi-sensory manner. This resonates with Piaget's (1952) theorisation of sensory-motor processes as providing the initial method of thinking and understanding the environment. Indeed, the distinction between implicit and explicit knowledge made by a number of theorists is often based around implicit knowledge of touch and movement. For example, Karmiloff-Smith (1992) suggests that implicit, procedural knowledge, such as riding a bike or successfully balancing weighted beams on a fulcrum, is possible because of non-conscious strategies for deploying touch and movement which children (and adults) cannot effectively verbalise (Messer & Pine, 2000).

The notion of implicit and explicit levels of knowledge has also been applied to spelling and reading (Critten, Pine & Steffler, 2007; Critten, Pine & Messer, in press). The exact relationship between writing and the physical activity of touch is difficult to assess, but studies have shown that typing and handwriting might be differentially beneficial, depending on the difficulty of the writing task and the motor abilities of the writers (Vaughn, Schumm & Gordon, 1992). For students with specific disabilities, technology-mediated writing is typically the preferred method (Vaughn, Schumm & Gordon, 1993).

Another related perspective is the importance of

touch as a characteristic of sharing everyday literacy practices. Auld (2007) identifies touch as a significant factor in her study of the remote Kunibídji community in Northern Australia. Having found that printed text made knowledge 'cold' and 'unchangeable' to the Kunibídji, Auld created talking books on touch-screen computers for the children to share in their homes. Here, the act of sharing digital stories was compatible with the everyday social practices of the Kunibídji community:

> The children established turn taking routines to maintain some form of social order around the computer which was in high demand. In one instance the children could be seen using the same routine with a buffalo bone … sharing the meat on the bone while at the same time sharing access to the texts on the computer. (Auld, 2007, p. 57)

Summary of theoretical framework

We have drawn on research from a range of disciplinary fields in an endeavour to scope out theoretical understandings of the role of touch in learning. To summarise, we conceptualise touch as a sensory resource operating within overlapping somatosensory and communication systems. Touch involves sensory responses and movement, and is therefore often linked to gesture, which we define as visible and intentional communicative action. We define pointing as a specific form of deictic gesture. When referring to the sensations experienced through touch we distinguish between three different sources: the sensations when gesture involves contact between humans or between humans and objects; the vicarious sensation of touch when observing the behaviour of others; and the notion of virtual touch when touching images on touch-responsive digital screens.

With regard to touch and literacy learning, we have considered a representative sample of research literature primarily from the fields of psychology and multimodality evidencing how touch and gesture are often integrated, how touch is used to signal joint attention, how it is used to share texts in diverse media, and how it often evokes enjoyable and implicit learning associated with sensory-motor processing. Drawing on Gibson's theory (1986), we regard learning as entailing a reciprocal relationship between a person and her or his environment, where the resources available have certain affordances, which offer differing opportunities for a person to act on. Building on this theoretical premise, our study aimed to investigate the literacy learning opportunities that touch-screen technology, notably the iPad, might offer students with moderate to complex cognitive and physical impairments.

Methodology

The study was conducted in a purpose-built special school located in the English Midlands for students aged 3 to 19 years. The school's extensive resources included a 'sensory room', music recording systems, hydro-therapy pool and a range of augmentative communication devices, such as eye-gaze control units. In a previous study (Flewitt, Messer & Kucirkova, in press) we introduced iPads to this setting as a comparatively low-cost technology to facilitate learning, and the school subsequently purchased multiple iPads for each classroom. Over the year prior to the present study, the iPads had been integrated into teaching and learning across the school, with some variability in their use across different classes.

In our previous study, we found that well-planned literacy-related iPad activities stimulated children's motivation and concentration, and offered rich opportunities for communication, collaborative interaction, independent learning and enthusiastic learning dispositions (Flewitt, Messer & Kucirkova, in press). In this follow-up study, we investigated how the iPads had been embedded in classroom-based communication and literacy, with a focus on the role of touch in learning. We made video recorded observations, field notes and audio-recorded interviews with the teachers of three mixed-age classrooms where students experienced a range of physical disabilities and/or associated learning and communication difficulties: Early Years (EY) (3–5-year-olds); Primary 2 and 3 (7–11-year-olds); and post-16 (16–19-year-olds). We also interviewed a small group of post-16 students and the school's ICT coordinator who supported the incorporation of iPads in pedagogic practice. The resultant data consisted of: field notes made over the course of one full school day in the EY, Year 2/3, post-16 and sensory classrooms; 13 video clips (total approximately 1 hour video data) and 4 interviews (total approximately 1½ hours). The interview data were transcribed, the video data observed multiple times, and key analytic themes were agreed between the research team, informed primarily by multimodal and psychology research. The school ICT Coordinator was consulted during our analysis and write-up.

This paper is therefore based on a focused data sample, collected in a school with which we were familiar from our previous study, and with which we had retained on-going contact. Whilst the findings must be viewed within the context of a single case study with a limited data sample collected during one day, our established familiarity with the setting and the richness of our observation data, supported by interviews with teachers and older students, permitted us

to explore in detail the role of touch during planned literacy activities with iPads. We followed BERA (2011) Ethical Guidelines throughout the research process and all names have been changed in the research reporting to protect participant anonymity.

Findings

We begin by adopting Kress's (2010) notion of affordance with regard to the physical properties of iPads and supporting apps, to clarify the kinds of opportunities iPads offered for learning in the study site. We then exemplify how for some students, but not all, the sensory and kinaesthetic performance of touch enabled and motivated them to achieve high levels of independence and success in literacy activities.

Literacy learning with iPads in the classroom

The observation and interview data revealed that in all the classrooms, the iPads had been incorporated creatively into the literacy curriculum, and stimulated enthusiastic responses from most students. Unlike more cumbersome equipment, such as desktop computers, interactive whiteboards (IWBs) and augmentative communication devices, the lightweight iPads afforded mobile, independent and flexible use: we observed iPads being used by individual students, in pair and small group collaborative work, and carried around classrooms to print or show work to teachers. The iPads were also taken into the dimly lit sensory room, where their bright screens could be discerned by visually impaired students.

The portability of the iPads combined with their touch-sensitivity and the responsiveness of diverse apps opened up new arenas for learning and inclusion for many students. In the post-16 class, students with complex physical impairment spent extended periods in weight-bearing 'standers' for physical therapy. These constrained students' access to desk-top technologies and often led to them being temporarily excluded from classroom activity. The iPad's small size and portability had led to an iPad workstation being created on one 'stander' and linked to an IWB. Using this workstation, students were able to complete cognitively challenging and collaborative activities during an otherwise tedious time, which contributed to the inclusive classroom community (see Figure 1*)* and the teacher appreciated as being 'good for the social side as well'.

In interview, teachers mentioned how touch-sensitive iPads offered students sensory access to literacy, and removed the need for students to use language to show their understanding – just a single touch could be sufficient to accomplish an activity. As the EY teacher commented, 'it's like a pathway to accessing

Figure 1. Shared activity with iPad on 'stander' and connected to IWB

through technology … things that the rest of us take for granted'. Students who were unable to access iPads with their hands were able intentionally to touch the screen with other body parts, such as their foreheads, and this worked particularly well with apps which did not require accuracy of touch, like Fireworks[1]. As the Year 2/3 teacher explained, the students 'do the smallest thing and you get the biggest reaction from them'. For these students, experiencing cause and effect through their actions, tracking movement on the screen with their eyes and understanding on-screen symbolic representation were all considered essential building blocks for literacy development.

However, the iPad screens and some apps were difficult to negotiate for some students, who found a large touch-screen monitor more accessible as it responded 'to a bigger gross motor rather than more fine motor like [the] small iPad screen' (EY teacher). The need for accuracy of touch therefore sometimes acted as a constraint to independent work, rendering students dependent on practitioners to perform fine-tuned actions on their behalf. Yet when this occurred, students' enjoyment and engagement in the activity through a third party did not appear to diminish their intense engagement. For example, we observed how one support worker, who was highly sensitised to 5-year-old Connor's communicative strategies, was able to successfully read meaning and intention through his blinking, eye-pointing and subtle changes of facial expression – acting as a conduit for his successful and enjoyable completion of iPad activities. We suggest this observation, along with many other similar observed events, exemplifies the 'incarnate relationship' between self and the world of others (Merleau-Ponty, 1982, p. 33), and suggests the close sensory link between touch experienced physically and vicariously through the actions of others.

1 Fireworks! Arcade™ is a free app designed By miSoftware for iPad and iPhone. The app brings up fireworks by tapping or swiping the screen. The stars can move and the fireworks light up the sky as users swipe the screen.

Touch and literacy learning

In his discussion of the importance of the sense of touch in virtual and real environments, Robles de la Torre (2006) suggests that 'the subtle, effortless performance of the normal sense of touch' (p. 24) is often taken for granted, compared to more readily apparent senses such as vision and hearing. By contrast in our observations of students experiencing disability, motor co-ordination and touch were far from effortless. Still, the iPad required minimal effort when compared to the precision and coordination needed for computer use, where students' attention was divided between a keyboard and a screen located in separate physical spaces. During interview, the post-16 students expressed an unequivocal preference for iPads, saying they found them 'great', 'easier' and 'better' than computers. Indeed, iPads enabled many students at this school to engage in writing activities in a relatively effortless and successful manner, as compared to producing texts by hand or computer. As the Year 2/3 teacher commented:

> iPads are brilliant for handwriting development and you only need the lightest touch to make a mark and a lot of great noises so you'll do something and you'll have this wow noise, whereas if you were doing it in the sand or in shaving foam you wouldn't get that … it would have a different sensory component.

As the teacher mentions, young children are often encouraged to trace letters in tactile media such as sand, paint or foam, in the belief that the action of tracing directs children's attention to a letter, which facilitates learning. With the iPad, tactile experience combined powerfully with immediate reward, such as a letter displayed on the screen or read aloud by a pre-recorded voice, which enhanced children's enjoyment and engagement.

Indeed, we observed many instances of digital touch offering students fun ways to learn, which were often linked to affective responses. For example, following a word recognition and phonics activity with conventional flashcards in the EY classroom, the teacher handed iPads to three young children seated around a small table, and to a further three children with complex disabilities seated in supportive chairs, each with a key worker alongside. As the children waited for the teacher-directed phonics activity to begin, they cradled the iPads lovingly in their arms, stroked them and smiled happily at each other, relishing the sensory and haptic exploration of these new media devices enveloped in softly padded and colourful protective jackets. With a variety of phonics-based apps, the children enthusiastically used touch to match letters to sounds, or to identify specific words from a jumbled selection of on-screen options, delighting as the selected words filled their screens, which they then showed to their peers and teachers (see Figure 2). In this activity, the iPad facilitated the seamless inclusion of all children in the same activity, acting as a focal point for their individual and collaborative endeavour, which drew attention away from the differing levels of support they each needed to complete the same activity. Furthermore, the young children's affective enjoyment of the iPads appeared to contribute positively to their engagement in the learning activity.

Figure 2. Early years class completes phonics activity

Although in interview the EY teacher expressed reservations about young children over-using new media at the expense of their social development, she recognised that iPads gave children fun opportunities to succeed effortlessly in their work with the slightest touch: 'even if they are very very physically disabled and cognitively impaired it's nice because it's so easy for them to succeed in.'

Many apps not only facilitated children's self-expression by responding to swiping and tapped touch, but also rewarded them with the sensory experience of real, vicarious and virtual touch. The Year 2/3 teacher recognised children's sensory experience as 'not just touching the screen but there are things like shooting stars so each time they touch it they are getting sensory reward'. This teacher felt that the simple act of touching, unlike other technologies, enabled students in her class to 'become a little bit expert'.

In the post-16 class, many students had high levels of literacy yet the teacher explained how they struggled physically to express themselves through most writing technologies:

> Not all students can access a laptop and sometimes it's frustrating because they're saying they want their writing in red because they used it in their communication aid but they cannot physically do it and that's what I like about the iPad is they can touch the screen and do a lot more than they can on the laptop … the iPad's got more to give for those that have perhaps got more physical disabilities and … they're more integrated with the group.

We observed students in this class creating book covers as part of an on-going project to produce illustrated stories on iPads, which they would ultimately print out and share with the EY class. For this activity, the teacher wrote three simple instructions on the whiteboard, under the heading 'About the author': '1. My name is …; 2. My hobbies are …; 3. My favourite part in the book is …' Seated in small groups, each with an iPad and working independently with the app *Pic Collage*,[2] with which they were familiar, the students set about their task enthusiastically and with deep concentration. One student, Tyrone, began by choosing a background pattern for his cover, then typed in his name and hobbies: 'going on iPad', 'using the computers and listening to music', along with his favourite part in the book 'iPad'. As he typed, he used spell check to correct any errors without needing to wait for the teacher's attention. Once he had completed the writing task, he experimented with different font and colour options (Figure 3a), screen layout, trying out different sizes, angles and positions as he used his fingertips to drag each element around the screen with consummate ease (Figure 3b). Once satisfied with his developing page design, he clicked on a link to 'Photos from Web', and began to browse and select images for his cover (Figure 3c). Once happy with his page, he shared it with his classmates, watched their responses and then fine-tuned its design, finally settling on the page shown in Figure 3d.

As Mavers (2007) discusses, the affordances of writing, both its potentialities and constraints, are subject to the medium in which it is produced. Although digitally-generated writing might preclude the personal 'touches' possible with pen and paper, digital media allow variations to the font, size, colour, emphasis, etc. of written words. For these students, the cognitive load of writing (or drawing or operating a mouse) when combined with extremely limited handwriting abilities would have been a heavy burden, yet the iPad afforded an ease of written expression through touch that was simply unavailable to them in other media. Undertaking this literacy activity on an iPad enabled each student not only to complete the task with a high degree of polish and aplomb, but also to 'take it whichever way they want to do it' (post-16 teacher), to be creative and to have fun. For example, Tyrone's classmate Gregory collapsed in giggles after completing his written sentences, attracting the attention of fellow students. Turning his iPad screen towards them, he watched them read his work with an anticipatory glint in his eye: 'My name is Gregory'; 'My hobbies are going on trains'; 'I'm the owner of Peter and Charlotte' (his parents). When this last sentence was read, his infectious laughter spread amongst the students and teachers, all sharing mutual enjoyment of this witty comment.

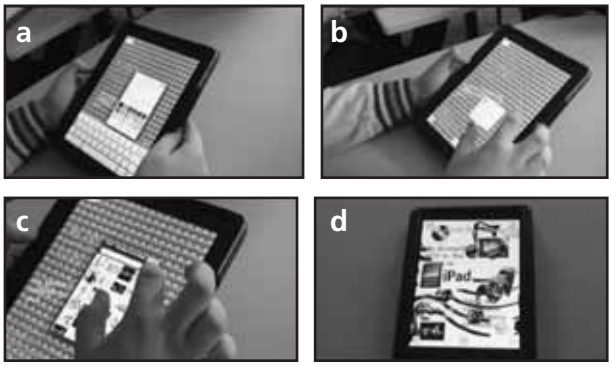

Figure 3. Post-16 student writing task on iPad

The texts created in this observed literacy activity were multimodal assemblages where 'writing' was clearly located as just one aspect of the students' work, along with design features and rhetorical devices, such as humour, which were enabled through their skilful orchestration of multiple on-screen and embodied modes. The students' deep engagement in this literacy activity appeared to be further enhanced by the inclusion of somatosensory stimulation in their writing, through physical touch (gently touching the smooth, hard surface of the iPad), vicarious touch (watching other students touching their iPads) and virtual touch (touching virtual objects on the iPad screen).

Discussion

Although this paper draws on a small data sample, its 'intensely local' focus of enquiry (Graue & Walsh, 1998, p. 8) has allowed close observation of the students' situated uses of touch with iPads. We now reflect on these insights regarding the way touch-screen iPads enabled independence and high levels of achievement for students experiencing moderate to complex disability, and created new opportunities for literacy learning. Finally, we speculate about the ways in which literacy and touch (real, vicarious and virtual) can come together in one digitally-mediated space.

Through our observations and interviews, we found that iPads afforded to students of diverse ages new opportunities for communicating their ideas through the overlapping yet distinct roles of touch and gesture. For students who had difficulty with fine motor movements of the hand, brief taps with the forehead or the side of the head were sufficient to indicate their engagement or set in motion a specific game or software program. When such touch was not precise enough,

2 Pic Collage™ is an app developed by Cardinal Blue. The app allows the users to arrange photos into frames, form collages, cut-outs filters, borders, stickers, and insert their own text.

students used 'eye pointing' to signal intent to their key worker, who completed the action for them. Although these students did not physically touch the iPad, they reacted animatedly to vicarious and virtual touch: through an adult enacting their intention, and through the on-screen consequence of the adult's action. Some students, however, continued to find iPad use frustrating, particularly if their physical dexterity struggled to 'keep up with the mental' (EY teacher).

We have applied Merleau-Ponty's (1964; 1968) phenomenological conception of the relationship between body and mind to our data, and have discussed how neuroscience research is adding new and anatomical dimensions to the reciprocal relationship between people and their environments in its suggestion that the somatosensory system plays a key role in our social perception (Keysers, Kaas & Gazzola, 2010). Future interdisciplinary research into students' uses of touch-screen devices would be fruitful to promote our understanding of the complex relationship between real, vicarious and virtual touch, and of the learning opportunities offered by handheld, touch-screen technologies, not only in terms of their portability, accessibility, flexibility and responsiveness, but also in terms of opening up powerful avenues for the embodied sharing of everyday experiences and narratives.

In this study, the comparative effortlessness, control and independence afforded by the combination of high end software design features and the iPads' responsiveness enabled many students, although not all, to achieve creative and skilled performance in a range of literacy activities of a nature that would have been inaccessibly effortful with other media. In the post-16 class, the accessibility of using touch for writing and designing texts facilitated a sense of empowerment for the students and freed up space and time for creativity and humour: they experienced what Robles de la Torre (2006) describes as layers of touch affording complex experiences. Without doubt, this sense of empowerment shaped the social environment in the class and instilled a strong sense of a shared learning community. In this class, the use of iPads on standers also facilitated greater inclusion, sharing and collaboration among students, particularly those experiencing profound disability.

Similarly in the EY class, we saw how young children were enabled by the touch-screen sensitivity of the iPads to outline letter shapes, in a far less effortful manner than handwriting or keyboard typing which require greater coordination. Together with the teachers, we therefore argue that engagement with iPads through touch offered this highly diverse group of students more accessible routes into literacy than traditional literacy resources.

Although we did not directly compare the various media available to students for writing, the observation and interview data indicate that writing on the iPad requires less grapho-motor control and facilitates visual and sensory learning. Vygotsky's notion of gesture being 'writing in the air' (1978, p. 107) is pertinent here as we consider the iPad to be a new cultural tool that offers a different kind of engagement space for literacy. With iPads, on-screen writing can be transduced from a digitally created artefact on the screen to a physical artefact on paper, i.e. writing becomes immediately visible and can also be printed off in a differently tangible form within moments. Unlike other media available to these students, where the hand-surface connection is mediated by another object (such as a computer mouse) physical touch and virtual worlds are intimately connected through the haptic affordances of iPads.

In this setting, we saw how the iPad was adapted and used variously to suit individual students, including those who were reliant on distal or core parts of their body for touch. Profoundly disabled students were able to exercise control with apps that required less precise touch, evidencing their emerging understanding of cause and effect and their engagement through implicit sensory-motor learning and exploration. As Merleau-Ponty (1962) theorised, the criss-crossing of the tangible and the tactile allows humans to project and integrate themselves with objects in the environment and to become one embodied entity. Our observations indicate that the virtuality of the digital worlds the students experienced through touch became entwined with the materiality of the physical world in their minds and bodies.

Underlying these observations is the way that the use of touch provided an intriguing mix of physical and virtual, implicit and explicit. The touch of the screen involved cutaneous sensations and feedback, as with any physical entity, however, many of the items being touched were not physical entities, but virtual artefacts constructed by others. In many cases these were iconic or symbolic representations of real objects. Taking this to a different level, touch also involved contact with the world of the web with access to information, images, video clips and social media. Thus, contact was being made with a virtual and social world, and the enthusiasm that this engendered provided a motivational force for literacy activities using apps on the iPad and also socially with others in the learning community.

Conversely, touching the iPads involved on one level procedural automatic responses, such as swiping to turn a page or pressing the home button to finish an activity. These touching processes were semi-automated,

non-conscious ones that became effective through trial and practice, as described by Karmiloff-Smith (1992). On another level, touch was also used in the service of decisions that were based on choice and conscious thought, as when Tyrone reflected on the design of his book cover. Here touch appeared to be in the service of higher order thinking and required the procedural semi-automatic motor skills to enable the conscious choices that were being made to be achieved efficiently and effectively. In this instance, touch was no longer exploratory access to the virtual, but manipulation of the environment to achieve specific learning objectives. Furthermore, touch was being used by students to project their personal identity within the classroom, as when they described their interests or made jokes about their parents. Here, touch was connecting through the virtual world to the social world of shared communication, language and emotion in the classroom (see Auld, 2007).

In conclusion, our findings are a snapshot of the rich touch-mediated communication and meaning-making endeavours of a particular cohort of students when using iPads in a special school. A longer term study would have enabled us to follow the learning trajectories of individual students, and a multi-site study would have afforded broader insights into the diversity of practices with touch-sensitive digital technologies. Nonetheless, our observational data have illustrated how iPads can enable many students to achieve independent, accomplished and pleasurable (if occasionally frustrating) completion of classroom-based literacy activities through the sensory mode of touch. Students' touch engagement with the iPads was integral to their involvement in both the social and learning fabric of their classrooms and allowed them to be physically and vicariously 'in touch' with their classmates, and virtually and figuratively with the wider society.

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