TOWARDS TURING TEACHING: TECHNICITY TO TRANSITION

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The words we use, when carefully considered, give insight into our thinking. The phrase "information and communication technology" (ICT), now elided to "technology," which encompasses pen and paper as well as its intended referent the [stored program digital] computer, on thoughtful examination is de-void of meaning: it is deeply vacuous. The cause is our ignorance of how the human, our species, is able to create technology. Given the power of the new medium, this is no longer acceptable. The Technicity Thesis seeks to fill this gap in our knowledge of ourselves, and provides an explanation of Platonic ideals. An evolutionary perspective, informed by a small extension to our concept of information to include 'quality' in analogy with grade of energy, suggests a fundamental transition for which evidence, once perceived, is abundant. The neurological substrate proposed is prefrontal access to phyletic information in primary sensory cortex. Technicity makes possible the delineation of three modes of learning open to the human. The first includes transmission of what is in mind by speech and learning by observation. Second is our ability to store knowledge externally to the brain by meaningful marks. The third came with the stored program digital computer – the conceptual Turing Machine – which adds external processing of information. Comparison of possible teaching method in each mode suggests that the Turing Medium is in tune with our mind. It can remedy confusions inherent in traditional primary school method and offers young children a neurologically healthier environment. Turing Teaching entails transition, thus it is impossible to research it within our existing schemas: engineering methodology is required. Political will, preferably at a European level, to provide a high quality, systematic introduction to working with computers in primary school, followed by a staged transition in literacy and numeracy teaching method, would greatly benefit children.

Keywords: ICT, computer, primary school, language, evolution, technicity, transition, modes of learning.

This paper is an essay in pouring meaning into 'information and communication technology' (ICT), a vacuous phrase that serves only to obscure the poor quality of our thinking about the role of the computer in education: specifically in the primary phase of school. Each word possesses great depth of connotation, most of which has been lost as educationalists elide them to 'technology' or to the empty acronym ICT. Because the language we use is critically important to the verbal communication of ideas, 'Turing' is introduced unambiguously and meaningfully to denote the entity under discussion.

The Cambridge Primary Review (Alexander, 2010) placed language development and discourse at the heart of the curriculum for five-to-ten year-olds. Alexander (2010) also sought to place ICT within the language domain. In so doing he is in concert with a zeitgeist that sees language, internalised speech (Vigotsky, 1962), as the heart of thought. Which, in a way it is. However, this lingual-centrism contrasts with our very obvious capacity to construct. Let us return our thoughts to technology.

Our unlikely planet exhibits all four key phases in the evolution of the universe: the transition form energy to matter, so simply captured in Einstein's $E=MC^2$, the unlikely emergence of life from the chemical debris of stars, and finally the extremely unlikely emergence of technology from a living organism. Papert (Harel & Papert, 1991), who's "Constructionism" took Piaget's constructivism onto a concrete, physical plane, is the only educational theorist to admit the primacy of technology. For Papert, learning "...happens especially felicitously when the learner is consciously engaged in constructing a public entity..." This formulation pulls focus from language and turns it on humanity's undeniably unique capability to construct. Thus, we come full circle, and re-state Comenius who was the architect of our current school system.

The difficulty that besets educational theorists is to be found in a lack of knowledge. We do not understand the 'how' of our technological capability (see e.g. Barrett, Dunbar & Lycett, 2002; Nolen-Hoeksema et al., 2009) for its omission). It is obvious that the technology we produce marks a transition in the evolution of the universe. Its simplicity of form has no precedent. For some reason we fail to note this last transition. But it is a sharp as the other three. Until we have a scientific theory of how our species developed the capacity for technology we lack a sound model of ourselves and thus a sound basis for a theory of education. At present we have two philosophies: an enquiry into the 'essence' of technology (Heidegger, 1977) and Papert's Constructionism in education. The Technicity Thesis is a scientific hypothesis that offers to provide an answer. In so doing, it also provides an answer to the question of Platonic ideals: e.g. "How do we know that red is red?" This question is the key to our capacity to construct.

The first step is to outline The Technicity Thesis and the evidence that supports it. However, as this is not the primary subject of this paper, readers are referred to Ó Dúill (2010, 2011) and www.logios.org for a more detailed discussion. The Technicity Thesis, in turn, provides a foundation from which to derive three 'modes of learning' and thus to define Turing teaching as a transition. This positions us critically to examine aspects of traditional primary school teaching method (in the basics) and to consider the impossibility of using academic research methodology in this domain. Of necessity, information from a number of disciplines will need to be introduced, for which no apology is given.

The Technicity Thesis

We may be confident that human beings are not the only species ever to speak (Deacon, 1997; Lewin, 1998; Dunbar, 2004a; Burling, 2005; Stringer & Andrews, 2005; Finlayson, 2010). The Neanderthals, our most recent cousins, had a brain similar to ours in size and architecture and similar speech anatomy. Parsimony requires that we presume they were as articulate as we are. Moreover, with a prefrontal cortex commensurate with ours, they had the same creative capacity to think, plan ahead, negotiate and focus on objectives. Therefore, it is arguable that much of psychology and the 'social brain' theory of human evolution (Barkow, Cosmides & Tooby, 1992; Byrne & Witen, 1988; Witen & Byrne, 1997; Dunbar, 2004b; Mellors et al., 2007) describe what we share with this species. Yet, Neanderthals, like any other primate, did not change the landscape to suit them. They lived off the land, as the land offered a living. Throughout their long evolutionary history, which is commensurate with ours given that we share a common ancestor, they never developed technology. Tools they had, but there is no evidence of the component-built tools that are the essence of technology. Nor is there any evidence of art – no Neanderthal graffiti – so no concept of line and colour. This contrasts with modern humans who have covered the planet(s and moon) with unnatural constructions and streets with graffiti. Occams' razor demands that this evidence of difference be economically explained. Heidegger (1977) in asking the question concerning technology sought the answer in language. The answer offered to this enigma is: quality of information.

Information, in its technical sense, is a fundamental property of matter related to entropy (Stonier, 1990). Maynard Smith and Szathmáry (2000) used it to map the major transitions in life: increase in information processing capacity is an available response to increase in environmental complexity, in accord with the principle of requisite variety (Ashby, 1971). The transition from reptilian to mammalian brain architecture is one such transition.

The mammalian brain differs from its reptilian precursor in the existence of neocortex, including prefrontal cortex. This enables a mammal to create a set of hypothetical futures from memories of the past. A pet dog will ask to go for a walk by fetching its lead in the knowledge that a walk is an option. Rats running mazes will enter an arm that never contains a reward out of curiosity. This is evidence of prefrontal creativity. But all these memories are sensory memories: memories of past events and places. In this sense, all mammals are sense-bound. Nothing can be created from information that has not first been a sensation.

In order to clarify our thinking it is necessary to introduce the idea that information comes in different 'qualities,' in analogy with the grade of energy. Like its energy analogue, quality difference is not expressible mathematically but in structural properties. The concept of information quality allows us to consider genetic information to be of a different (higher or more fundamental) quality than its phenotypic expression or idiosyncratic sensation. There is such a quality of information available to the brain: phyletic information. This information is genetically inbuilt and exists at central nervous system level. It is typified by somæsthesis, the internal sense that provides awareness of the body and its integrity and which is the source of such medical syndromes as phantom limb and neglect. In summary, phyletic information is encoded in the genotype and expressed in the structure of the phenotype.

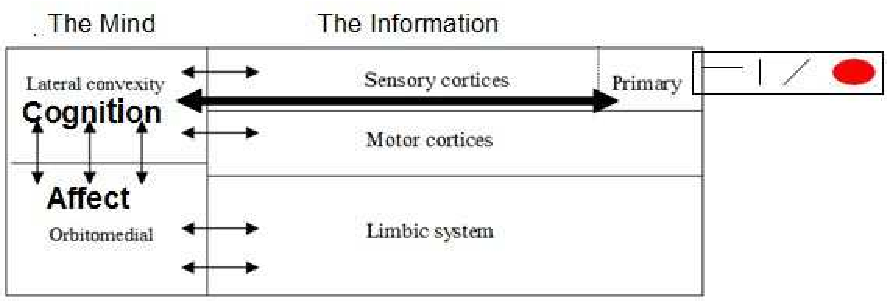
We are now in a position to offer an answer to the question of the redness of red. Ball (2002) reports a person who had retinal colour-blindness yet had a concept of pure primary green. This is possible because our genes contain information on pure colour. Phenotypically, this is expressed in certain feature detector neurones that react along a red-green continuum (Hubel, 1995). Thus, for primates, colour information is available as an index of sugar content, e.g. to determine that fruit is ripe. The human abstract concept of pure green or red is possible if and only if the reaction of those neurones is available independent of sensory context. This implies a somaesthetic-like connection from primary sensory to prefrontal cortex. Primates do not have such a connection but psychophysical evidence (Crick & Koch, 1995) suggests that the human does. The Technicity Thesis, a proposition for discussion, dissection, disputation and disproof, asserts that:

> *The evolutionary transition to the human occurred when prefrontal connection to phyletic information in primary sensory cortex was established. Information on: line, primary colour, etc. became available for appreciation and creative construction. Over generations, with education, this made the development of technology possible.*

In the human the seat of the 'mind' is prefrontal cortex, which provides working memory and temporal integration. It is highly reciprocally interconnected with the older parts of the brain and the neocortex. Of its two equally highly interconnected divisions, the orbitomedial has relations mainly with the older brain and the lateral convexity mostly with neocortex, both sensory and motor. Thus, sensory and motor memory is stored in neocortex and processed in the prefrontal area in response to the needs of the organism conveyed from the limbic system, which prefrontal cortex also modulates. The proposition is that certain phyletic information in primary sensory cortex reaches prefrontal cortex unbound to context. There it can become a concept and, consequent on cognitive/affective interconnection, an aesthetic experience. In addition to memory from the sensory life-history of the individual, information that is fundamental to the internal structure of the universe (e.g. wavelength of electromagnetic radiation) is made available for awareness and creative recombination by prefrontal cortex. Information of this form known to be available at primary sensory cortex includes the classes: line length; line angle; direction of motion; colour pairs red-green, blue-yellow, black-white; and pitch, all properties of matter.

When present in prefrontal cortex this information may become a concept and, consequent on cognitive/affective interconnection, an aesthetic experience. Schematically, this is expressed in fig. 1, below.

Figure 1. *Schematic of the proposed neural connection for technicity*



The human can conceive and appreciate pure red or a perfect square – and use it as a referent. This proposition is entirely consistent with the principles of brain evolution (Striedter, 2005) and of the development of prefrontal connectivity (Fuster, 2008), of which it entails a very small extension. It is, therefore, entirely consistent with Darwinian principles. The power of technicity comes not from any significant change in architecture but in quality of information. That is, the transition to technology flows from information quality. As a result, the human can construct meaningful marks and mechanisms. From the adaptive need to maximise this creative constructional capability flows the process that we call education.

Beyond language

Without doubt, language is fundamental to our life-style. Equally, language is unarguably complex. For many this complexity was an argument against its evolution and in favour of its invention. This was reasonable because we can invent new words and alter the grammar, in contrast with the fixed biology a complex organ such as the eye. However, the evolution of language is now established (Pinker, 1995) and is intimately associated with the social brain hypothesis of hominine evolution (Dunbar, 2004b; Burling, 2005).

The work of Bloom (1993) with infants suggests that speech expresses to others what is in mind but not supportable from context. I.e. speech lets us communicate about things not present, past events and future possibilities. This parallels the function of prefrontal cortex. Bloom also remarked that the ‘something in mind’ is also expressible by sign language. This demonstrates that there are more routes to expression than the evolved speech adaptation. Although we use language for internal conversation as well as in interpersonal discourse, this should not blind us to its limited capability to express what modern humans have in mind. And, although there is increasing evidence that language reflects certain aspects of how the mind works (Pinker, 2008), there is no evidence (Fuster, 2008:195) for Luria’s prefrontal localisation of the internalised speech that Vigotsky (1962) proposed as the stuff of thought. However, co-evolution of language and the brain may have provided a substrate for a general capacity to create and manipulate arbitrary symbols (Deacon, 1997). Consider the drawing below, figure 2, as an expression of what was in the mind of an eight-year-old child.

This complex spatial representation is packed with what linguists call nouns, adjectives and prepositions, with hints at verbs. Its composition has taken place in prefrontal cortex, from the elemental information immanent in the structure of primary sensory cortex, in accord with grammar-like conventions. We tent to interpret it as art (Gardner, 1980) but it is not. Looked at objectively, this picture has more in common with an architectural drawing or an engineering blue-print than with a photograph or painting of a scene. Like the writing it incorporates on the shop-front, it is consists of geometric forms. Here these forms hint at a scene and the objects in it, as in writing they hint at speech. Language cannot express this information. As the Platonists noted, we have the word “red” (or *vörös* or *черен*) but how do we know ‘red’? Language can only communicate knowledge once meaning is agreed. Not only must the referent be a part of the common cognitive culture, the linguistic culture must also be shared.

Figure 2. *A drawing by an eight year-old*

Diagrammatic representation, as the LEGO Company knows well, transcends the boundaries set by language diversity. But expression in this powerful medium must also be learned. It is no accident that the curriculum of the kindergarten features colour, shape, number and letter learning: this is the first phase in bringing the technicity adaptation on stream. Throughout the primary school years, maturation of prefrontal cortex, virtually complete by their end, will integrate language and technicity as parallel means of expressing what is in mind. This is a part of the process of changing children's chatter into Alexander's (2010) discourse – which will culminate in the possibility of inspecting language in its written form for clues on how the mind works. Its genesis is illustrated by the classic child's story with its associated drawing that we see displayed on classroom walls.

Externalised memory

Memory, perceptual and action, is what prefrontal cortex works with. Technicity makes it possible to store memory externally. This external memory may be static, as in the frozen discourse of text or an image; or it may be active, as in a mechanism or machine. Knowledge stored independently of a mind becomes an object of sensation. Hence, it may be incremented as each successive generation stands on the recorded shoulders of its forebears.

One strand in this process is of particular relevance to the discussion here. It is the confluence of the study of language and mathematics, which writing made possible, with the development of electrical and mechanical engineering. In the conceptual Turing machine (Penrose, 1991) these streams came together and are realised in the now ubiquitous stored program digital computer. Until this happened, the storage and processing of information were separate domains, the latter usually the province of the human mind. Both processes entailed a long apprenticeship in coding, decoding and animation. Schools for over six millennia have taught literacy and numeracy with a presumption that information cannot process itself. This is no longer the case.

The human mind is now in a position to pass beyond merely externalising, thereby extending, sensory and action memory. It can externalise, and thereby extend, its processing capability; i.e. prefrontal working memory. This is the new medium environment that school faces. This is why the term "Turing medium" is a better descriptor than the vacuous phrase "information and communication technology" (ICT). The latter both fails to differentiate computer-based media from their unanimated precursors and signals deep ignorance about our technological capability. The former connotes the capacity of the medium to read, write and, with a little instruction, do arithmetic. These operations, at the heart of school, may now be carried out externally to the brain: with consequences for our concept of education.

Within the human institution of education, the primary phase is paramount. The years of primary school are the most active phase in brain maturation, particularly the connectivity of that seat of thought, the prefrontal cortex. According to Fuster (2008:202):

> *"… the temporal-integrative functions of the prefrontal cortex – attention, memory, planning, develop* pari passu *with its structural maturation. Those functions develop gradually, with spurts between 5 and 10 years, to reach completion at about 12."*

Modes of education

The institution that is school is not a prerequisite for survival. We have available to us all the cognitive apparatus of our hominine predecessors, notably: language, recognition skills and memory capacity. If technologies are lost, as happened with the Tasmanians (Diamond, 2005), survival is little compromised until faced by a technologically more advanced competitor. Language, in a tribal group at least as complex as chimpanzee troupe, provides a particular advantage. By expressing 'something in mind' that is not supported by the immediate context, language becomes an interface other minds and thereby to distributed information processing. A linguistic community, in planning and problem solving, is reliant on not minds operating singly but on minds operating in concert. Such a community may also distribute knowledge. Hence, what is in an elder's mind becomes more important than their physical capabilities.

Additionally, hominines have the ability to learn by observation. (This may involve so-called mirror neurones). Seen in embryo in chimpanzees (Matsuzawa et al., 2001), we experience it when we ask how something should be done and it is demonstrated with the injunction, "Do it like that!" Learning by observation, like language, has deep evolutionary roots. This is the primary way we learn in day to day practical situations and transmit culture. This is Mode 1.

Mode 1 learning: A combination of spoken instruction where the immediate context cannot provide support and observation if context is sufficient. This mode uses only upon our inbuilt biological capabilities, including a capacious memory, and it accounts for much of human learning. Given the similarity of our brain and speech adaptation with that of the Neanderthal, this is a mode of learning that we both probably inherited from our common ancestor. As we share it, let us characterise it as "Neanderthal." It relies heavily on memory and linguistic mnemonics. Memorising multiplication tables, learning the Koran by heart and practising the piano are examples. In a social-brain based society it also relies upon knowing who knows. This, in pre-information societies, leads to the role of teacher as subject expert or master.

The constraint on mode 1 learning is limited and impermanent memory capacity, even where enhanced by distributed memory. In addition, transmitted language suffers from information degradation ("Chinese whispers"), linguistic drift and language diversity. It therefore serves only to maintain knowledge that can be verified in experientially – and to sustain myth. The technicity adaptation enables these constraints to be relaxed, leading to modes 2 and 3.

Mode 2 learning: Meaningful marks and mechanisms provide external perceptual and action memory capacity, thereby making it possible to 'carve in stone' the 'something in mind' that we wish to express. This applies equally to the recording of language and the construction of mechanisms. All are what Papert termed "public objects open to inspection." They include multiplication tables, the Koran and the piano. Are all products made possible by the higher quality neuronally structural information to which we have access. All human knowledge, recorded in libraries and embodied in mechanisms, has accrued generation on generation by this process. However, before meaning may be understood, the record must be decrypted and, where appropriate, animated. The Victorian 3Rs – reading, writing, and arithmetic – were the core of school in Sumer six millennia ago (Kramer, 1981), and they remain so. Such learning may be characterised as lithic, reflecting the clay tablets in which writing was impressed. This term captures the fossilised state of the record and the need to bring mental processing power to bear on it to decrypt the marks and extract and re-animate meaning. The consequence for primary school children is a heavy mental work-load. They must learn to decrypt and animate information frozen onto a medium that offers little or no assistance. Mode 2 overcomes our biological memory limitations, and has been extremely successful. Nevertheless, importantly, there remains the limiting constraint of human information processing capacity, which the lithic medium stretches to its limit.

The constraint on mode 2 learning is that all externalised information must be understood and processed within constraints set the limits of biological mental, working memory, capacity. This capacity constraint is captured in Miller's (1956) 7±2 rule, (hence, computing with a 5/2 abacus may be visualised,) and experienced in the depth limits of human intentionality and phrase embedding (Dunbar 2004b). The bounds of evolutionary biology remain.

Mode 3 learning: The Turing machine, physically objectified in the stored program digital computer, breaks the final bond to biology. It provides us with the capacity to represent processes externally and thereby relax the constraint that all animation of external memory must take place within the mind. I call it "Turing" learning, in honour of the genius whose war-time work was suppressed by government and who was hounded as a homosexual by the same authorities. However, there remains a constraint. The Turing machine can only carry out mechanical operations. There are aspects of human thought, as Dreyfus (1992) and Penrose (1991) have argued, that extend beyond the mechanical. It is this aspect of the human intellect that Turing media now allow to come into the foreground.

By relaxing the processing constraint, Turing learning poses major challenges to current educational method, particularly in the primary phase. Firstly, the capability of the medium to carry out the very operations that are the focus of primary schooling throws down a curricular challenge to educationalists. Should literacy and numeracy remain at the heart of primary education, devouring a significant part of childhood, as Alexander (2010) complained, when the medium can provide alternative means of access to information? Secondly, it offers to the primary school child an assistive medium when learning to decrypt the meaningful marks of writing and number and in animating them. Here is a second challenge to educationalists, this time in terms of method. Should teaching method in literacy and numeracy remain book-oriented or should there be a transfer to the medium that can assist the child in their learning? Turing learning, it may be argued, offers the primary school child, in the vital years of rapid prefrontal connective growth, the possibility of an education more in tune with neurological development than has hitherto been possible. It also opens up a new possibility: greater focus on those mental capacities that extend beyond the mechanical. This possibility exists because there are emergent properties after a transition. One such possibility is hinted at by the process of instructing the computer: the new discipline of programming. At a minimum, this activity can extend children's experience with text. Transition to Turing learning brings significant change. The question is, "How far are we into the transition?"

The current situation

Given that, before The Technicity Thesis, we lacked any understanding of ourselves as a technological species and defaulted to language as our highest cognitive capability, it should not be surprising that our education system currently operates in Mode 1 supplemented by lithic media. Alexander (2010) is correct in emphasising the importance of language in this phase, if not its primacy. Clearly, a child entering primary school has this Mode 1 available and has yet to conquer the medium of Mode 2. The current practice of 'integrating ICT' into primary education entails assimilating computer technology to the existing educational infrastructure, curriculum and attainment requirements. There are currently two significantly different approaches to this, typified by English and Bulgarian practice respectively.

English practice was well described by Cartwright and Hammond (2007). It takes a scattergun approach to computer-based technologies and seeks to introduce children to them within the curriculum. Based around classroom computers, teachers and children use ICT as a tool. Whilst both teachers and children become familiar with current technology, the result is that children are not taught to work with the computer systematically nor do they learn to use the full range of its possibilities. Consequently, by the end of primary school children in the same class have had very different experiences and reach very different levels of capability, capability that often reflects home circumstances more than school learning.

Bulgarian children were offered a curriculum that focuses on mastery of the medium from 1998 (Ilieva & Ivailov, 1999). This is reaffirmed in the current curriculum, introduced in 2006. Children are systematically taught how to work with the computer in a dedicated computer room by a teacher with specialist training. Attainment targets for each year of primary school are set. Supportive software is provided for the initial stages (Ivailov & Ilieva, 2005), with set lessons for all four. A project oriented approach, with activities related to the normal school disciplines for their age, is used. Thus, the outcome of every lesson is a product in which each child has invested their developing knowledge and skill. By the end of primary school all children in the class will have commensurate capability.

Both education systems, however, insulate extant curriculum and teaching method from the computer, particularly in the basics of literacy and numeracy. The English national literacy and numeracy strategies (Gov.uk, 1998-2011) explicitly promoted traditional teaching methods, thereby keeping the computer at bay. The Bulgarian system simply retained existing method, books and standards in these areas. Where lessons in the computer room impinged on other disciplines, they served to enrich rather than transform the children's experience.

In neither paradigm are the assistive possibilities of the computer as a Turing medium exploited. No change in method has occurred and no change is being considered. However, the Bulgarian approach is to be preferred because the children fully experience, and begin to appreciate, the different capabilities of lithic and Turing media. This is a step to transition.

The transition problem

The perception of the place of ICT in English primary education, which may well generalise internationally, is ambivalent. Alexander (2010:226) reported that: "The division between those who regarded ICT as a cross-curricular tool or skill and those who believed it should be timetabled as a subject in its own right was marked." And he noted (2010:242) that in Rose (2006) "…science had been supplanted as the third 'basic' by ICT [within] 'skills for learning and life'". The Cambridge Primary Review's final position is summed up in the following extract from Alexander (2010:270):

> *"But warnings about any technology which in an exceptionally short space of time becomes such a prominent and almost addictive aspect of young people's lives should not be lightly dismissed. Further, we believe that this debate confirms that it is right to locate ICT within the language curriculum rather than as a semi-detached tool and uncritically fostered 'skill for learning and life' as in the Rose report, for placing it here enables schools to balance and explore relationships between new and established forms of communication, and to ensure the developmental and educational primacy of talk, which is now exceptionally well supported by research evidence, is always maintained."*

This is highly revealing of the view of education that pervades academic institutions. The hole in our knowledge results in little or no recognition that our species has a unique capability to construct, (see Dunbar, 1996 – for a discussion of technology blindness). Given that Mode 2 learning goes by default, it is not surprising that there is little recognition that what is called ICT might be a new medium that has a new and powerful relationship with the human mind.

In a formal sense it is impossible to research a transition from the viewpoint of a prior phase: the outcome of a transition includes a set of emergent properties upon which there can be no information prior to the transition. For example, the modern human lifestyle is totally unpredictable from the information available to the Neanderthals. On a more prosaic level, but for the same reason, it is not possible to pose a meaningful research question related to change of medium. This is why only the 'integration' (assimilation) of ICT to extant method may be researched. But there is a way forward: the engineering approach.

The engineering approach works by identifying inefficiencies and proposing solutions based on technological advance. The history of highpressure (strong) steam power is an example (Trevithick, 1872). Richard Trevithick proved his point by demonstrating that less coal was used for the same work. But before he could do so, he must devise the technology and pilot its application. Engineering methodology is: Identify, Devise, Pilot and Evaluate.

The place to look for inefficiencies is the basics. As Alexander (2010) has emphasised, literacy and numeracy dominate primary education; are taught by traditional methods; with constant concern expressed about levels of attainment. Low attainment in them is associated with lack of economic opportunity and criminality. Developmental dyslexia has been offered as an organic explanation for learning difficulties in these areas, because these skills correlate poorly with general intellectual ability. In both number and writing, teaching method relies on brute memory; yet in adult life assistive Turing media will be used.

Literacy will be considered first. English is taken as the target language for two reasons. Firstly it exhibits most strongly the drift of spoken language away from the written form (a technology) over time. A second reason for the choice of English is its widespread use as a lingua franca. Therefore many children who do not have English will be learning to read and write English as a second language in primary school. Other languages such as French and German where the written form was standardised some centuries ago are similar, whereas languages like Irish and Bulgarian that were subject to spelling reform in the middle of the last century have a lexicon closer to speech. However, even in these languages, the inevitable effect of dialect and elision disturbs the one to one mapping of sound to spelling. It is a myth that speech sound and spelling can be related one to one (see Taylor, 2008 for a discussion in relation to speech synthesis). Even reference dialects, e.g. Received Pronunciation or General American, map very poorly to spelling. Jenkins (2000) found that for international English, intelligibility requires a common core of speech sounds commensurate with the letters of the alphabet. We may take the view that written language is a communication channel parallel to speech for the expression of what is in mind, cf. signing. This is consistent with the finding that experience of text is the best predictor for success in literacy (Adams, 1990; Rose, 2006).

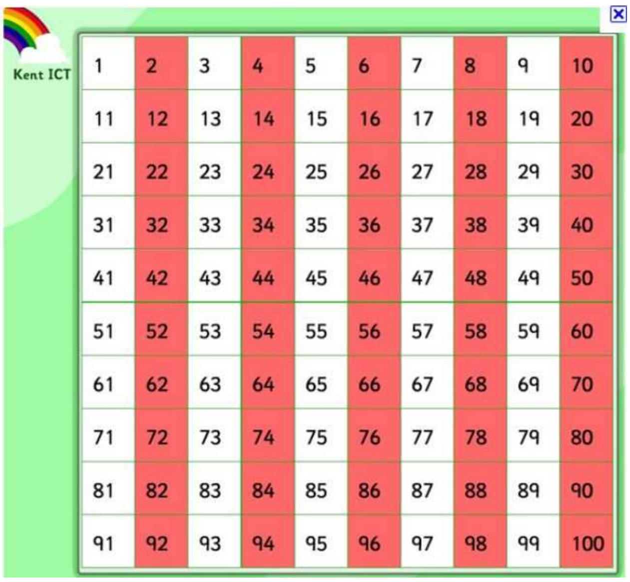
Writing is difficult for young children who must both recall and construct letter forms at an age when their fine motor skills and shape recognition are still developing. Recognition and pointing is easier than recall and formation. Therefore a computer keyboard and screen can scaffold the early stages of writing. On-screen, the font, its form, size and colour, and the background may be altered. This may pre-empt certain visual difficulties that lead to reading failure. With the Turing medium the expressive, writing approach to literacy – which parallels the expressive path to oracy – becomes viable.

There remains the question of scaffolding the learning of meaning and spelling. The spelling checkers and auto-correction of adult word processors are a solution to the failure to learn in school. It would be preferable if children were given a good mental model of spelling, one that exposed the underlying systematicity (Crystal, 2002). Naturalistic text-to-speech is of negative assistance in respect of spelling: compare the reference pronunciations of words with their spellings in the Oxford English Dictionary. Spelling reform is misconceived. Elegantly researched, the initial teaching alphabet (Downing, 1967), based on bringing the orthography closer to speech failed in the classroom. A conceptually better approach is start from writing, where each letter is given equal weight, and factor in Jenkins' (2000) common core speech sounds. For this, it is necessary only to provide some twenty distinct letter-to-sound mappings. These may then be appropriately computationally concatenated to produce an acoustic analogue of the text. For young children in kindergarten and primary school, such an approach is viable because they are at the point in neurological development where they can learn new language sounds with facility: they learn a second language with no trace of mother-tongue accent. Children of this age also adjust their speech sounds to the audience, often using a high status form in school and dialect at home. This means that they can keep parallel pronunciations in mind. The computer system proposed by Doyle (1986), he called it 'autex,' would offer an assistive parallel pronunciation system to scaffold the learning of spelling.

Numeracy is the other notorious skill that some children fail to master, even after many years at school. And yet, as Alan Turing said, numbers should be their friends: they are reliable and never let you down. Given the ubiquity of the four function calculator and the historic desire of mathematicians to be relieved of the tedium of computation, is the objection to young children using this capability of the computer well founded, or a myth? Is the best route to numeracy through the chanting of number words and the counting of heaps? How does our mind understand number? And how does our technology represent it?

The question of how we understand number is best answered through the language window. In common with other primates we naturally use real number (Gallistel, Gelman & Cordes, 2005), and name people and things in preference to numbering them. Recent research (Spaepen et al., 2011) suggests that counting is not a good entrée to computation but that language is. The language of number, taken with the 7±2 rule, indicates that we count up to nine then chunk into higher-level unit; cf. the operation of an odometer. The place-value numeral system we use today mirrors this. When we do count collections, we tend to chunk in fives, e.g. the prisoner's five-bar-gate (~~1111~~) method of recording the days. The 5/2 abacus used by the Romans and modern Chinese also nicely resides at the lower end of our mental capacity, so practised users are able mentally to visualise computations, thereby internalising the concrete technology. It is disconcerting, therefore, to find that counting in tens and representations such as the 'hundred-square' (figure 3) are recommended for use by children.

Figure 3. *An example of a 'hundred-square' used for introducing computation*



The conflict between the place-value numeral system, which chunks and shifts register on the count of ten, with the hundred-square representation, which starts a new row on the count of eleven, is obvious. The counting frame and Dienes apparatus, by chunking after nine, also stretch mental capacity beyond its normal limits. In so doing, might they inhibit learning?

The calculator, technology founded in the linguistic expression of the manner in which mind manipulates number, may be a more effective route to computational competence and comprehension. The symbol system maps one-on-one to language, of which it is a parallel representation in the visual domain. It therefore seems reasonable to use the computer's capacity to add without error to scaffold computational capability in children. Doyle (1986) reported the case of a primary school child who was offered this route to numeracy in the face of an inability to count. It is certainly preferable to the current transition from oral to written, pencil and paper, arithmetic where the medium offers no assistance and errors are corrected by the teacher well after the thought process.

It is clear than traditional method is inefficient, and possibly ineffective for some children, the question is how to implement change in method and measure improvement? Neither question has a simple answer. The transition from lithic to Turing medium is fundamental. It radically alters teaching method. It places new demands on developing minds and will have unexpected outcomes. One is the possibility that children may use number and writing at an earlier age. This offers a route to capability through application rather than practice: the project oriented approach that is implicit in the English primary school topic and explicit in the Bulgarian project-based approach to teaching children to work with computers. This suggests that the measure that we need will be based on an assessment of the quality of children's products rather than on the demonstration of isolated skills.

The Turing medium is programmable. This is its defining property as a medium. It is intrinsic to the difference between lithic and Turing media. It follows, that if children are to master the medium, they must experience programming. Given that the aim in literacy and numeracy is to maximise experience with text, and a computer program gives immediate feedback, the act of programming may be seen as an expression of the basics in the new medium. Because programming is a means to this end and not an end in itself, non-graphic (i.e. text-based) programming environments are most appropriate. Logo, in its various implementations, has attempted to offer a suitable environment. It uses the letters and numerals the children and learning and contains grammatical markers. Thus, writing a Logo program is analogous to writing natural language. The difference is that something happens. The key to suitability for the primary age-range is in the choice of what we choose the language can make happen: the microworld to which the language relates. Technicity suggests that the target would be some aspect of the adaptation that has begun to emerge. For instance, children like to change the colour of the text they are writing. Word-processors allow them to do this by point and click. Logo, on the other hand, offers them 'settextcolour' as a command. Thus, they have the possibility of 'writing for the computer as a responsive audience' and thereby extending their experience with text.

It is very unfortunate for the perception of programming in education that Logo was introduced through the 'turtle geometry' microworld. The root problem for primary school was that this microworld tried to teach programming on the back of concepts of shape and space that children in primary school were only just experiencing. Turtle geometry is a very sophisticated concept, an academic conceit cultured in the minds of two very able academics (Abelson & diSessa, 1981). For children who are beginning to assemble the basic elements of line and angle into shapes (and will assert that a square rotated 1/8 turn is a diamond), draw chimneys at right angles to a roof, and are just learning how to conceive paths to escape from a simple maze, this geometry is not appropriate. The authors should have been alerted to this by the “triangle” and “house” ‘bugs’ they found in children’s thinking. Unfortunately, Papert (1980) chose to major on the Turtle in “Mindstorms,” his visionary work on children and computers. He reported another ‘bug’ of similar form: the “bugged man” as he called it. As a solution, he invented the concept of “body syntonicity” as a way for children to internalise “Turtle Talk” by walking shapes. There was no scientific basis for this notion. However, in identifying a somaesthetic sense, he had identified the correct quality of information. The Technicity Thesis identifies the source of motion information as neurologically separate from that for shape – as the curriculum distinguishes shape and space. Primary school teachers rightly rejected turtle graphics. Logo had become synonymous with this microworld and the activity of programming was rejected with it.

There remain excellent Logo implementations that can be used in primary school, notably Comenius/Imagine Logo and LCSI Microworlds. The former has the capability to generate stand-alone software and was used to program ToolKID, the Bulgarian introductory software. The physical Turtle, as a controllable external object, was more appropriate and this aspect of programming continued in LEGO/Logo, a combination suitable for primary school. However, the LEGO Company replaced Logo with LabView, adapted professional control software that uses images of components with parameter boxes. The aim of this was to align technical LEGO with the STEM agenda. Consequently, the possibility to build control naturally into a situation (Ilieva, 2010) is replaced by isolated prototypes under the subject heading of robotics. This parallels original the agenda for Logo, which was developed as an aid to learning mathematics. It is virtually impossible to promote programming as a means of expression in a novel medium: its referent is computing, an element in the isolated subject system that exists in the university – a structural division inimical to primary education.

Engineering transition

Current teaching method is undoubtedly inefficient, ineffective and, for a significant number of children, demotivating. Repeated complaints about school leavers’ literacy and numeracy skill attest to this. However, the development of new teaching method will take a significant amount of time. Moreover, because the change is focused on a change in medium, it will not be possible to compare the results with existing practice. This is because the skills that are taught to decrypt and animate text will not need to be learned as a prerequisite. They may be developed along with other learning. Thus, all our norms for attainment in the so-called basic skills will cease to be valid. Although the children will clearly show whether the new methods are less onerous and more effective, proper scientific evaluation will be needed. The nature of the computer medium makes it possible to provide a continuous record of child-computer interaction for analysis and ongoing assessment. Given that current practice is inefficient it should be possible to agree measures that demonstrate more rapid and effective learning.

Only from within a transition can you have any information about likely emergent properties. The early days, post Trevithick, in the development of the railways (Smiles, 1857) provides an appropriate model for a process of transition from lithic to Turing medium. The focus of the enterprise must be on people with practical knowledge of what is evolving. Only from within a primary school classroom can you gain the information on how children's thinking and learning changes. Only with an expert knowledge of the developing primary school child can you begin what will be a lengthy process of transforming teaching method. Development of Turing teaching will be effective only if placed in the hands of practising primary school teachers who have a clear understanding of the nature of the computer as a medium.

Transition is a process that requires continuous input and evaluation. However, the need for a number of steps, or stages, is indicated.

- The first is to ensure that children are systematically taught how to use the medium by a skilled teacher. The Bulgarian approach and curriculum demonstrates the necessary conditions.
- The second is to develop and pilot Turing materials for the teaching of literacy and numeracy skills. These have already been outlined (above). Once these materials have been used and refined by children and teachers in the classroom, method may be formalised.
- The third is to increase the availability of primary school teachers who are adept with Turing media.
- The fourth step, for which the third is prerequisite, is to restructure the primary school curriculum. Clearly, both skills and knowledge are at its heart. The question is: What skills and what knowledge? The author of the first Bulgarian national curriculum for working with computers in primary school argues convincingly for the construction of physical models to be given greater emphasis in primary school. She has demonstrated that by systematically teaching LEGO$_{®}$ construction children's understanding of the real world can be enhanced, their aesthetic sense extended, teamwork skills be built, discussion can be focussed, and programming can be introduced as a natural extension of talking about the actions of realistic elements built into models based on control systems found in their environment. This type of activity enhances the development of technicity in the neurologically significant primary school years. It is essential, given the effects our species is having on our habitat.

Of these steps, the first is in place in at least one national education system. It is effective in assuring equity of access and consistent and coherent outcome. It puts into place a foundation.

Step two is the key to transition. It cannot take place within existing national school systems, curricula and attainment targets because it entails a transformation. Until the nature of the transformation and its practical consequences are understood, there is nothing to implement. Therefore, as with the railways, small scale pilots are required. Transfer of the 'basics' to an assistive medium will require the greatest thought and development. There are significant conceptual difficulties in relation to number. How is an assistive medium that is in tune with though best used to develop an understanding of and capability with number, as opposed to inculcating dependency on the machine? Beginning reading will require even more thoughtful development. The 'autex' proposal, for which space precludes a detailed discussion, entails more than simply stripping ersatz prosody and pronunciation rules from a naturalistic text-to-speech synthesiser. For each written language a standard set of sounds that map one-on-one to letters and work effectively as a spelling mnemonic will need to be identified. The widespread teaching of English as a second language in primary school makes it an obvious candidate for prototyping. However, the problems in initial reading are the same for all European languages and the "autex" proposal is language independent in its form. There need only be a single set of sounds for each language: a standard sound for a standard alphabet. As an engineering problem, this is easier than localising naturalistic text-to-speech. Turing method will need a careful and thoughtful process of research and development.

The schools used will, of necessity, be experimental. The schools may be private or public. The funding and oversight may, likewise, be private or public. However, the children who learn in this new environment will need to assent to the process.

Europe has a range of languages, educational traditions, infrastructure and resources. The EU has the necessary administrative infrastructure in place and there are enough medium-competent primary school teachers for step one. A small network of development foci funded through the EU would appear possible starting point.

Discussion

The Cambridge Primary Review has been timely in that, through emphasis on language and discourse (Alexander, 2008), it acts as a foil to The Technicity Thesis. A moment of reflection on primary education reveals that at its core is the technology of record: meaningful marks. The absence of any science of 'how' the human comes to be able to create such marks, such technical entities, Papert's 'public object open to inspection,' undermines i discourse that is the Review. Lacking a cognitive framework for technology, it cannot discuss constructed objects on an intellectual plane. The technicity adaptation alone gives the human something to talk about beyond the gossip of a reciprocally altruistic social animal. It is these 'things' that lead us to concepts like entropy or the Turing machine, hardly subjects for dinner-party talk (Snow, 1963), that stop us trying to invent a perpetuum mobile and set limits on mathematics. It is for such concepts that education is prerequisite.

The Technicity Thesis takes the vernacular words under the administrative acronym ITC and uses the great depth of meaning with which technology has imbued them. The empty phrase is replaced with a meaningful technical term that honours a scientific pioneer: Turing media. Communication, the language upon which Alexander (2008) and all primary school teachers place such emphasis is 'language beyond gossip' that is an index of cognitive development. Thus, the primary school topic, constructed LEGO situations and a product oriented approach to ICT provide an intellectual context for constructive talk. The language lesson helps this by shaping ill-formed daily chatter into a formal structure that facilitates precise communication, an issue to which Oppenheim (1992) vigorously alerts social science researchers.

Finally, Alexander (2008) nicely illustrates the impossibility of researching the outcome of a transition with the conceptual framework of the preceding phase. The absence of academic knowledge about technicity, our capability for technology, meant that the researchers, through no fault of their own, were unable to think constructively about the relationship of technology to primary. In its absence, no amount of expertise in experimental design, statistical analysis and discourse analysis can create meaning: there must be an appropriate 'something in mind.'

Primary school is about the genesis of technicity, our truly unique evolved adaptation. The medium used and its relationship to our neural processes is fundamental. A record-only medium demands a particular set of capabilities. A record-and-process medium makes very different demands and offers very different opportunities. These are, as yet, largely untapped. Therefore there is a need for a discussion of significant depth about how the transition of teaching method, and thereby learning, from lithic to Turing medium might be catalysed.

Conclusion

This Technicity Thesis at the heart of this paper originated in a concern that the computer was not being used in schools effectively for the benefit of children, particularly in the primary school years. The attempt to analyse this led to the realisation that psychology and education had no theory about how the human comes to be able to draw. We could not give a scientific explanation of our capacity for technology. To provide one, it was both necessary to identify the emergence of technology as a transition equivalent to the emergence of life and extend the concept of information/entropy to include a notion of quality analogous the grade of energy. The gap in human psychology may now be filled and an explanation of how humans come to be the only technological species is on offer. We have an explanation of Platonic ideal forms in terns of neurology and information quality.

Returning to the original objective, we may now take a very different perspective on primary school education from that currently on offer. The language presumption is replaced by a testable scientific hypothesis: technicity. The genesis of technicity through kindergarten and primary school, in concert with prefrontal maturation, forces a review of the perceived pivotal role of language. We may again say of education: “Let no one ignorant of geometry enter;” because it is geometry that comes on-stream in the primary school years.

Language is essential for verbal communication, as in this paper but it is not the stuff of thought, nor is it the defining capability of our species. Language is an adaptation of great evolutionary depth that we share with most mammals. Education is technology based. First we developed technology for the external storage of memory then we extended externalisation to the representation of mental processes. We now have three modes of learning, each defined by the characteristics of its medium: Neanderthal – pre-technological and pre-human; lithic – based on a static record and the current foundation of school; and Turing – computer-based and offering new cognitive opportunities.

The Technicity Thesis, to which the conceptual framework of the Cambridge Primary Review is inimical, emerged from the classroom and was motivated by child behaviour that current theories of learning could not explain. It offers an economical explanation of our capacity for technology and sharpens our perspective on language. It raises questions over the capability of academic institutions in matters of practice: recall that Robert Stephenson spent only six months at Edinburgh University and that father and son later promoted Mechanics Institutes to develop engineering skills and concepts. In the light of a blindness to technology in academic culture, it calls into question the language-focus of our education system and the capability of the university in matters of primary education. Transition to Turing teaching offers the greatest challenge to educationalists since meaningful marks made formal education possible.

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