Technicity, T-concepts, Turing Teaching and Elementary Robotics

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Abstract. The proposition of the technicity adaptation is finalized and the existence of two qualities of concept derived. Entropy considerations show the forms created by the technicity adaptation have greater power than environmental information. The thesis is applied to the process of education and three modes of learning identified; the third being dependent upon the Turing machine, the name of Alan Turing is taken as its eponym. Some consequences for school are outlined. The question of robotics in elementary education is considered in relation to child cognitive development and two approaches compared for suitability. Finally the need to embed robotics in the development of Turing teaching and a proposed way forward is discussed.

Keywords: Elementary education, human evolution, technology, psychology, robotics.

1 Introduction

At the past two robotics workshops I presented a new approach to thinking about the relationship of the human to technology and tried to apply this notion to robotics in education, particularly in the primary phase. The added element, strangely for psychology but naturally for engineering, is the second law of thermodynamics. This is achieved by the introduction of concepts of entropy and information; very apt in the centenary year of the birth of Alan Turing. These considerations lead to the identification of two very different qualities of concept; both already well known but now well defined. This framework allows three modes of learning to be defined, based on the medium used; in contrast to Papert's two [1]. Application to education is again restricted to the elementary phase of education, from four to fourteen years with emphasis on the primary years, because it is cognitively the most complex.

2 The Turing Machine

When Alan Turing demonstrated the limits on mathematical computability, his work mirrored the lambda calculus of Alonso Church but with a twist: Turing included the mathematician. In so doing he introduced issues of entropy and the constraints of the second law of thermodynamics. The Turing machine can no more compute without the expenditure of work than could Maxwell's demon so sort molecules. The read-write-erase head cannot move along the infinite tape and thus change the state of the machine as if it were a perpetuum mobile in defiance of the second law. At a stroke, Turing turned mathematics into a physical science. This implies that issues of entropy, the physical counterpart of information, must inform any consideration of the capacity of human beings both for mathematics and technology (and their confluence, science).

3 The Technicity Thesis

This proposition concerning how humans evolved the capacity for technology has been developed by the author over a number of years. The neurological mechanism proposed is invasion by neurons from (lateral) prefrontal cortex of primary sensory cortex. This is illustrated in figure 1. The type of information available at this point in the nervous system is consistent with accepted elements of modern human behaviour. The proposed adaptation is consistent with the timescale depth associated with these characteristics, with principles of brain evolution, and the trajectory of hominine brain expansion [2,3,4]. It also excludes language as the basis of technical capability and places the co-evolution of complex language and the social brain within evolutionary time scales associated with the genus Homo in general. However, the thesis to date provides no basis for understanding the power and simplicity of technology. Entropy considerations resolve this issue, and a plausible explanation of human technological capability becomes a formal scientific proposition [5].

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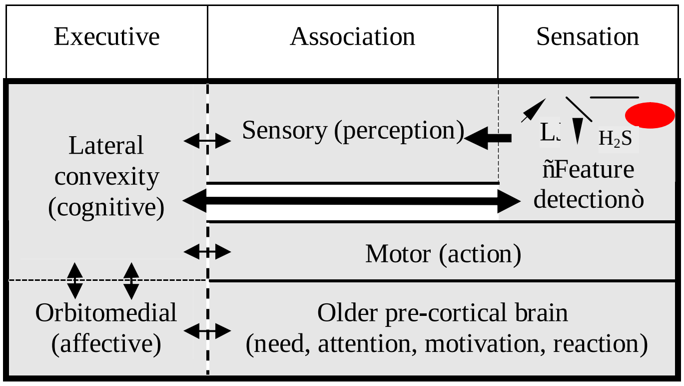

Fig. 1. The architecture of the technicity adaptation. Extension of prefrontal neuron connection to the genomic information available in primary sensory cortex (*arrow passing through the unshaded area*) may be compared with the normal perceptual route (*connections through the shaded areas*). The type of information made available by the technicity adaptation from so-called feature detector neurons is illustrated symbolically

3.1 Genome, phenotype and information quality

When the Platonists puzzled over the ability of the human to conceive the redness of red they raised a fundamental question about information. The technicity adaptation resolves this by making available to cognitive processes information on pure red, i.e. on photons of about 470 THz. This information is not sensory information from the environment. It is information built into the structure of the phenotype. It follows that it is the genotype that possesses information on the frequency of photons, which it structurally expresses in the fleeting phenotype of the species. This implies that the genotype has information on a property of matter that the human, the phenotype, has only recently been able to describe; (and implies that the human has a species-level concept of the redness of red). It is obvious that the genotype must possess a large amount of information about properties of matter in order to construct a phenotype.

The genotype is much less complex than the phenotype it constructs: the information it possesses is represented as combinations of four bases. This implies that the genotype is of far lower entropy than the phenotype it builds. Thus, all biological entities are of high entropy relative to their genotype. Sensory information entropy is commensurate with phenotypes, i.e. relatively high. In the case of vision, the information at the retina will reflect the complexity of the environment. It will have high information content. On the other hand, the frequency of a specific photon is very precise: a simple piece of information of low information entropy. Low relative entropy can provide power for work [5].

3.2 Primary sensory information

Information built into the so-called feature detectors of primary sensory cortex, although not directly representing a property of matter like photon frequency, is all of low relative entropy: line length and angle, direction of motion, pitch, the primary colors red, green, blue, yellow, black and white, and others not yet located. This is genomic information expressed phenotypically in a structure used by the organism to construct sensation. The term construct is used advisedly because all information carried by photons impinging on the retina is lost in the photochemical reaction that leads to a nerve impulse. A nerve impulse is merely a symbol written on a Turing tape and has relevance only in terms of the state of the machine; in other words, meaning only in the context of information already available to the nervous system. In order to see red the brain must already have information about photons of about 470 THz, in accordance with the principles of control theory.

Were prefrontal cortex (pfc), the most creative computational unit in the brain and seat of working memory occupying some 27% of neocortex in the human [6], to gain direct access to this unassociated information, the possibility of constructing novel low-entropy concepts of would arise. Note that direct connection to pfc bypasses normal perceptual processes and the language system, see 4 below. Low-entropy concepts, by definition, give rise to simple low entropy constructions. Hence, technology is far simpler than biology. The ultimate source of simplicity is information on properties of matter possessed by the genome. This is why technology is low entropy and thus of greater power than natural biological

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forms. The early evidence of modern humans processing red ochre into a pure pigment supports this proposition.

Ochre processing also offers another dimension of support: aesthetic. The two highly interconnected divisions of pfc differ: one is largely cognitive, the other affective. Low-entropy information reaching the prefrontal area also induces affect: colors are pleasing. Here we see the origin of the aesthetic that is so important to the human psyche and the educational process: the same source for art and technology.

4 Concepts matter

An illustration of both the quality of concept that technicity makes possible and the higher entropy of environmental information, even where derived from a construction of technicity, is shown by figure 2. Both shapes are constructs of technicity; they both have four equal sides and four equal angles: mathematically and conceptually they are both square. Yet, the act of rotating the image a one-eighth turn results in a perception of a different object, for which the word "diamond" comes to mind. This effect is significant for scientific thought. It implies that the human, uniquely, has two routes to concept formation: the high entropy channel of sensory perception and low entropy technicity constructs. The square/diamond effect shows the two routes to produce concepts of differing quality, with consequent cognitive conflict.

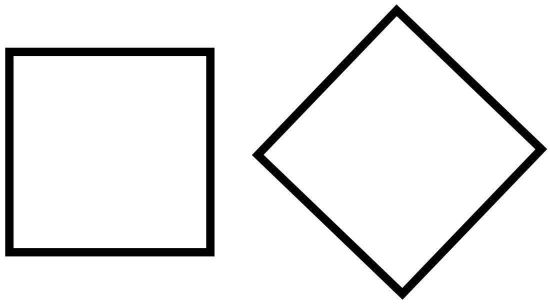

Fig. 2. The square/diamond effect demonstrating V- and T-concepts. Both are products of technicity and both are square but the characteristics of the perceptual system lead to the perception, and naming, of two different objects.

Perceptual processing has the greater evolutionary depth and is linked to language, as the illustration demonstrates. The constructions of technicity are: unique to the human, of recent evolutionary origin, unsupported by biology, and unconnected to language until they exist in a perceptible physical form. At present we have no vocabulary with which to differentiate these two qualities of concept. It is proposed to remedy this by using prefixes. The concepts that arise from technicity will be T-concepts, the letter T both to signify technicity as their source and in honor of Alan Turing, whose thinking assisted in the development of the concept. The concepts that arise from perceptual processes and are directly linked to spoken language will be called V-concepts. This both signifies their perceptual/verbal character and recognizes Lev Vigotsky who first described so-called internal speech and transmission though social intercourse.

A number of works on science education have noted the difference in quality between these two qualities of concept and the need to offer a route from V-conceptualization to T-conceptualization. In the case of the square/diamond, the simple act of rotation provides the necessary cognitive conflict. In other fields, confronting V-concepts that have great plausibility can be far more difficult, particularly where the V-conceptual nature of an assertion is not immediately obvious [7].

A notable example is in number, its history, the language of number, and current teaching method. Most tally methods of recording bundled numbers up into fives and tens: one-to-one correspondence to fingers on two hands. The Roman abacus and numeral system reflected this. Other European counting frames and checker-boards tended to be based on ten. Language, as spoken, appears to have a similar base. However, inspection of the written form demonstrates that this is not so. Language is consistent with the place-value decimal notation. I.e. the mental 'register' increments up to nine then overflows. This triggers its zeroing and unit-incrementing of the next higher register. Decimal calculators work on this principle. At a V-conceptual (perceptual) level number seems to be based on groups of ten, and is taught this way, e.g. Dienes apparatus. At a T-conceptual level, language reveals that the mind works like a calculator; which is probably why we can invent one. V/T concept conflation in early number

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teaching may well inhibit learning. This is why the distinction between the two forms of concept is so important for education. The power of socio-verbal perceptual V thinking to misdirect thought is great and the process of instilling a T-conceptual approach to thinking is key to understanding the character of the primary phase of education. How well this is achieved is illustrated by the math example above.

4.1 Powerful forms

Low entropy graphic forms are not the sole prerogative of geometry. Writing systems, including numerals, make use of them. In the case of writing, there has been a steady development in the technology. Beginning with pictograms (icons) which stood for objects and numbers, written language recorded speech stripped of prosody. Over a long period it developed into an alphabetic form that can segment the speech stream not only into words but into sound units. Technicity points to the graphic form of writing as the source of the cognitive capacity to achieve this. Similar development took place with number where notation systems that were mere tally recording were replaced by the Hindu-Arabic place-value system. In number the graphic change also signified a shift from V-concept to T-concept. Roman numerals mirror finger-counting whilst place-value reflects the working of the mind; revealed by the language of number. Place-value notation was devised after language had been made an object open to inspection by writing.

In parallel with the development of notation systems to support memory and mental operations, physical forms based both on geometry and an emerging understanding of the properties of matter were invented. Although the Turing machine was modeled on an individual with paper, pencil and eraser to compute the computable, it was the physics of electricity and properties of materials that made possible the electronic stored program digital computer. This powerful form combines information on properties of matter with notation that reflects cognitive processes, to provide a medium capable of carrying out processes hitherto the prerogative of the unique human mind.

4.2 School

The technicity adaptation makes a very specific demand upon human children: they must go to school. Although the architecture of technicity is genetically determined, bringing it on stream in the primary school years, when prefrontal connective growth is at its maximum, is highly influenced by experience. Technological knowledge cannot be absorbed from social and environmental interaction. Techniques need to be taught. Education has developed alongside technology and three distinct modes of teaching and learning may be identified.

Vigotskian. The first is the socio-verbal mode that was identified by Vigotsky. This is a mode that we shared with the Neanderthals and which has a deep primate heritage. It consists of verbal instruction and demonstration/observation. Based on language and perceptual processes it is an effective means of inculcating V-concepts.

Grammar. Writing is the basis of the second mode; made universally available by the printing press. Here the graphic medium relieves and extends the capacity of memory. Unfortunately, the low entropy of writing entails a long apprenticeship. Children must be schooled in the grammar before they are able to decrypt, encrypt and animate the record. It is the present basis of education systems. This mode will be designated Grammar schooling. The capacity to write language does not imply a similar capacity to generate T-conceptual thinking, quite the reverse. T-conceptual thinking in this mode may arise only from direct study of properties of matter using non-linguistic technologies. V-concepts and T-concepts may exist in parallel; and have frequently done so in the history of science.

Turing. The third educational mode exists only in embryo. Its medium is the stored program digital computer, the Turing machine. The Turing medium can read, write and, with a little instruction, do arithmetic. In other words, the medium itself has the capability to assist children in the process of learning to use powerful forms. This offers potential relief to the onerous apprenticeship in grammar, once a suitable curriculum has been devised. One obvious aspect of such a curriculum would be the use of mouse and keyboard. The keyboard, in particular, offers the possibility of writing on screen without looking at the fingers: letters flowing like notes from a musical instrument enabling the text to be observed and considered as it is written. At a cognitive level, Turing media can help resolve the V-

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concept/T-concept conflict between counting groups of ten and computing in base ten and the similar conflict between speech and writing, discussed elsewhere. Turing media also add a range of new possibilities, one of which is robotics: the physical and notational combined. (The word ñmediumò is used to redirect from ñICTò and ideas of robotic instruction to teaching tuned to the developing mind.)

Table 1. Some characteristics of the three modes of learning.

Neanderthal (Vigotsky)	Grammar	Turing
Socio-verbal and observational	Textual	Computational
No external medium	Externalized memory	Externalized memory and processing
High memory load	Demanding Long apprenticeship	Assistive
Environmental entropy	Mixed entropy	Genomic entropy
V-conceptual	V/T-conceptual	T-conceptual

5 Robotics method

Elementary education requires not only a curriculum but teaching method that is cognizant of child development from infancy to puberty. During this period all the connections to orbitomedial prefrontal cortex are established, as are the majority of cognitive to the lateral division. Connections, affective and cognitive, and their strength are a function of childhood experience. In the primary classroom, as the technicity adaptation comes on stream, cognitive conflict between V-conceptual and T-conceptual thought begins. This makes it conceptually the most complex (and interesting) phase of education.

The possibility of Turing teaching makes imperative clear and careful articulation of the integrated developmental nature of this phase. In elementary school there are no isolated subjects as understood in higher education, and no specialization. This phase of education abhors what it terms splinter skills.

To teach children to work with the computer is to develop their knowledge and skills in using the capabilities of the medium through activities normal for their age; which is arguably best achieved using a project oriented approach. Robotics is one component of this and must be both developmental and flow from the children's knowledge of their world. This demands not only that robotics make use of children's developing skills but that it directly contributes to the development of those very skills.

5.1 Critical consideration

At present, largely because Turing teaching does not really exist, working with the computer supports Grammar schooling without affecting teaching method; or enters the classroom as isolated projects. This is illustrated by two recent reports. The Cambridge Primary Review [7], whilst highlighting the onerous nature of the literacy and numeracy apprenticeship, failed to recognize the computer as a potential solution; the focus was on its socio-verbal aspects. The Royal Society Inquiry into Computing in Schools [8] narrowly focused on teaching computer science; its Chair commending "Scratch" as an easy introduction to the subject. Whilst the first takes no step towards Turing teaching the second makes computing a splinter skill. These two failings are seen in most approaches to elementary school robotics. Robotics has been included in the elementary curriculum on a project basis in support of the STEM agenda rather than the curricular whole. This is reflected in the character of the materials aimed at this sector, of which the products of the LEGO® Company are excellent examples. WeDo product is specifically aimed at children in the primary years of schooling and yet it fails the Turing teaching test.

WeDo or don't. LEGO® WeDo™ is supplied as a kit of LEGO elements; USB hub with a 50cm lead to which a motor, a tilt and a rotation sensor may be attached with short 10cm leads; pictographic software based on LabVIEW; and an activity pack with step-by-step instructions for assembling and programming a dozen different mechanisms. A concession to the mindset of the target population is the toy-like character of the constructions: e.g. a top spinner, an alligator that opens its mouth and a boat that rocks on an imaginary sea. With a 50cm USB lead, the constructions must be close to the computer that controls them. Similarly, sensors and motor have short leads so must be co-located. As supplied, this precludes their incorporation into a constructed scenario that models, say, wild animals or the sea and safety, the sort of wider topic at the heart of primary education.

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The step-by-step instructions are educationally questionable. A toy bought as a Christmas present certainly benefits from the classic LEGO illustrated assembly instructions but in school the aim is the capacity to create. This is seen most clearly in literacy where children learn how to combine letters to express thought and where copy-writing is considered a means of practicing form as a precursor to creative activity. The WeDo projects are all ‘copy-writing’ in this sense and, as isolated prototypes, do not lead to the development of a more general creative constructional capability.

There is no software link to primary school literacy and language objectives. The pictograms reflect a pre-alphabetic and pre-computer age where written language was separate from the constructions of technicity. In practice, the superficial simplicity of pictures can also be problematical. WeDo does not require the children to tell the computer what they have connected to it; the USB system does this automatically, without comment. So, children are not asked to think about the elements they have connected. In choosing from a palette of pictograms to assemble a sequence of operations, it is possible to build a program that waits for input from a sensor that is not present. The program can be halted only by use of CTRL-ALT-DEL, the red STOP button having no effect: a telling design defect.

This contrasts with the obsolete LEGO Dacta Control Lab and the original LEGO Technic interface. In both, though the interface connection was short, the wires to the elements were long. Programming, whether proprietary or Logo, used the letters and numerals the children were learning to write with, and words linked to language development. Programming was precisely telling the story of the action rather than cutting and sticking a pictorial image of the activity. (And ‘stopall’ did what it said.)

6 We are where we are

Hindsight is generally unhelpful; but if illuminated by new concepts, a view of past groping in the dark can help in projecting a route forward. For Papert, ñconstructionism,ò the notion that creating physical objects open to inspection was a more felicitous way of learning that verbal instruction, was an article of faith not a scientific hypothesis. Whilst there is a flood of material on the so-called psychological effects of technology, the ôhowô of technology is as visible as the far side of the moon: present but unconsidered. The academic domain of psychology has, to date, shown no interest in the genesis of the aspect of human behavior that is technology. There is only philosophical speculation [ref]. Referencing absence of studies is notoriously difficult. However, introductory psychology texts [ref] and literature search attest this unfortunate state of affairs. It is necessary, therefore, to work from first principles.

Entropy is a property of matter and information familiar to robotics engineers; as is the second law of thermodynamics. The technicity thesis is an exercise in their application: a) by inspection, a single cell is more complex that any technological entity. Less information is needed to describe technology that biology therefore the former is of lower entropy. The second law insists that it is impossible to pass locally from a higher to lower entropy state without doing work. Life, powered by low entropy photons from the sun, has progressed from low to high information processing capacity as Darwinian processes increased environmental variety. I.e., organisms progressed by increasing the information on properties of matter possessed by the genome and expressed in the phenotype. This is a basic principle of information engineering; and technology has followed a similar path. A tadpole drawing by a four year-old, whose brain is only beginning to mature, is impossible if considered in terms of signal processing on the percept of a person. The information for its construction must reside within the brain. The drawing reveals the initial stages of access to it as the brain connects up and the emerging capacity to compose with it. (The proposed adaptation is consistent with brain evolution and neurogenesis.) The information embodied in the drawing, again by inspection, is of lower entropy than any environmental perception. It is therefore, by definition, more powerful; capable of supporting higher quality cognition. This is obvious in its application in geometry to measure the world, in writing to tame the language instinct, and in mathematics to reveal the workings of the mind.

Drawing, in the square/diamond effect, teased out the concept-quality difference for which the terms V- and T-concept have been coined. The difference is exemplified by the geocentric/ heliocentric issue: perceptually, the sun revolves around the earth; geometrical considerations show the converse is true. Now the two concept qualities with differing bases and differential intellectual power are delineated: the powerful T-concept rooted in properties of matter; the everyday V-concept a product of perception and socio-verbal processes. Now, we may understand how the technicity adaptation elevates human technological capability above language. Now Papertôs constructionism has a scientific foundation.

Education is directed towards the development of technicity capability in children. Though, lacking an understanding of this, the unique human adaptation, we describe what we do to children in other terms. Current educational thought is essentially V-conceptual. The socio-verbal is elevated above the technological despite clear evidence that at the core of education is the mastery of technologies that

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offer: power over language; the capability of artistic expression; and entrée to scientific thought. Education is based on belief not science. As with all faith-based systems the possibility of abuse is high and a dispassionate examination of Grammar schooling evidences this. The medium is demanding and unassistive and the process of schooling can be very abusive. The psychology of abuse suggests that the abused will return to continue the cycle, resisting any change to a system which they thrived.

6.1 Transition to Turing teaching

The transition to Turing teaching has only one inhibitor: belief. The resource issue has been resolved: serviceable computers suitable for primary school are now being thrown away. The belief blockage is best illustrated by arithmetic. Oral (Vigotskian) mental arithmetic is prized as a sign of mental capacity. Grammar schooling offers children a representation of number as characters frozen on the page. The learner's task is to animate them. Again, the capacity to do this is taken as a measure of intellect. On the Turing stage, computational characters know their roles and can act them out. This relieves the learner of memorization and mental computation. It also gives the teacher no sums to mark and the authorities no standard assessment tasks. The child, on the other hand, can explore, internalize and then apply numerical relationships with much reduced stress. The technicity thesis, using entropy measures, tells us that this is cognitively the more powerful approach.

Change of medium implies a change in cognitive processes, which are established as a child's brain matures during the primary school years. Therefore, transition is can take place only this educational phase. It is also the phase in which medium change is the most difficult because apprenticeship in the book-as-medium is a major aspect of this phase. Thus, whilst the Turing medium is incompatible with Grammar schooling, its methods of assessment and standards, there is the necessity of transition from the old medium to the new. Here is the conundrum.

Technicity not technology. Conundrums may only be solved by careful use of language. The usage of "technology" does not imply careful use of language, rather the converse. Technology, in the form of marker and surface defines the Grammar school. Technology in terms of the computer defines Turing teaching. Both are information and communication technology. Current use of the word technology is socio-perceptual, more of a Dawkins' meme, a Vigotskian virus infecting thought. Technology per se changes nothing. Change occurs when the relationship of the medium to the mind is fully understood.

Mind Matters. School begins on transition from kindergarten. The four to five years of primary school are mentally the most tempestuous of a childŝ life. How the childŝ mind is formed in this phase is very dependent on experience; not the type of experience necessary for infant language development but the experience necessary to release the power of the technicity adaptation. This is a twin-track task: a) to develop technicity itself, most clearly seen in drawing, coloring and construction; and b) so-called language development. The latter is academically perceived as the major concern of primary schooling. However, when taken with literacy the viewpoint changes to that of bringing language under cognitive control. Primary school teachers talk about this in terms of teaching children to think. The importance of this endeavor is highlighted by the recognition that the primary human communication medium is spoken language. Technicity makes possible its written counterpart ï a Papertian inspectable object ï that may further assist thought. In primary school, all curricular streams are tributaries to this objective.

A journey begins with a first step. But who takes it? From where the lead comes is vitally important. In the case of Turing teaching, this step was taken by a primary school teacher in Bulgaria at the end of the last century. Conceived in a state school, this curriculum was developed in a private school that was willing to assign two class-periods per week to both working with computers and LEGO construction, through all the years of primary school. It was adopted nationally by the Bulgarian government. In this context, the curriculum was framed as a number of elective modules [11]. These are:

1. Working with graphic information;
2. Working with text information;
3. Working with sound information;
4. Working with animation and video;
5. Combining different types of information;
6. Programming (Logo)
7. Control of physical objects and processes with the LEGO-Logo system;
8. Working with subject-oriented applications;
9. Working with Internet;

10. Get control of computer system; and
11. Basic information actions.

This curriculum remains in place but an obligatory elective version was implemented in the early part of this century. This removed the robotics and programming modules. Supportive software, ToolKID, developed by Ilieva and written in Comenius Logo is used primarily in the first two years.

The objective of the curriculum is mastery of the medium by the children. This implies mastery of it by their teachers. To catalyse this, teacher training was developed and books for both teacher and pupil written. Schools that elected to deliver this curriculum were supplied with a computer room where each child, or at worst two children, could work on one computer. Though clear attainment targets are set for each school year, the weakness of both curricula is that they are not assessed and schools may elect to teach only certain modules at certain stages in the school year. The original allocation of two class-periods per week is seldom provided. Mastery of the computer as a medium is not, as yet, considered a basic skill that demands systematic teaching. Nonetheless, a first step has been taken.

Creativity. The method for the whole of this curriculum emphasises creativity. This is described in the following terms:

> *[T]he use of the new technologies was oriented towards helping the entire development of the child's personality, not to the acquisition of professional skills. Some main goals were specified ... work guided and supported by a teacher. These goals were attained by a project-oriented approach that is considered fundamental in the process of education. Children define goals and implement their ideas in projects that are based on personal experience and important events in their lives.*

Thus, even where contributing to other school disciplines, including literacy and numeracy, the method encourages creativity.

Robotics. As the modules show, robotics is an integral part of this curriculum. The descent is from the earliest computer control systems, including the LEGO Interface A: lamps, motors, sensors. The LEGO Logo environment offers the necessary combination of programming and construction: both of which the children learn systematically, starting from first grade. The LEGO bricks offer a math/mechanical environment that supports the math learning. The Logo programming language provides an additional occasion to work with text; and experience with text is crucial to success in literacy. But programming is more than this. It is a way of telling a story. The question is: What story to tell?

Consider six year-olds. What are they learning in school? What knowledge do they bring to robotics that they can incorporate in a situation that they model in LEGO and Logo? Whatever natural language they have as a mother tongue, they will be starting to learn a second; most likely English. What do they know about technological control: switching on a light. Programming this in LEGO Dacta Control Lab is simple English: talkto ñlampa on. A model of a town or village with street lights and lamps in houses interfaced to a computer provides a first step on the path. It roots robotics in the childôs own world and not in a fantasy of the entertainment industry. Add motors and sensors and other situations that children progressively understand and there is progression. As models become more complex the stories that may be told about them increase. Programming will naturally become more complex. In the context of English as a second language, naming procedures in Logo offers a means of expressing knowledge of its structure and vocabulary. That Logo has syntax and punctuation may used to engender reflection on the conventions of the written form of the language they loosely speak but with which their capability is increasing. It is notable that Control Lab was designed for secondary education and that a fortuitous continuity with LEGOôs previous product made lamps available and so offered a starting point for six year-old children. This is not so with WeDo, which highlights a fundamental issue.

Top down or bottom up? In Ireland there is a tale about a traveller who stopped to ask an old man for directions. ñHow do I get to Dublin?ò asked the traveller. ñWell, sir,ò replied the old man, ñIf I were to go to Dublin, I wouldnôt start from here.ò This nicely encapsulates the conundrum of robotics and programming in school. The point of departure, vide MIT and Tufts University, has been the academic discipline. WeDo has software ñsimplifiedò from the professional. The constructions are ñkiddiefied.ò They start the journey from the wrong place in the hope, vide Scratch, that surface child-friendliness will offer an easy entry to their subject. This is not the way education works. The journey begins when the child enters kindergarten and rapidly accelerates through the four critical years of primary school. It follows that the initiative needs to come from primary education. But here is another conundrum: how do primary school teachers, who both understand children and computers, influence the administrative-academic nexus that controls education. They have no official research role. They receive no financial support. Their career is not advanced by research reports: they receive no points for papers.

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The way forward. The first step is not to ask what robotics we teach to the youngest children in school but rather what is in the mind of the child: how do they see the world, what do they see in the world, how might we help them to express what they know? For certain, they see no robots: to them the word implies a fictional humanoid. They do know about things found in the home; on the street. When they begin to describe these and how they work: they are on the way to modelling and programming them. They know about their own senses and those of their pets: they are on the way to working with sensors. All that is required is that the robotics curriculum and method reflect what the childôs minds can offer.

The first step in the transition to Turing teaching is the same as that in Grammar schooling: mastery of the medium. The approach developed by Ilieva in Bulgaria provides a tried and tested first step on the road to true Turing teaching at European level. The approach takes on board the assistive nature of the medium: children are taught all the possibilities of the computer (mastery) by means appropriate to their age (no curriculum change) by a project-oriented approach (no exercises) in an aesthetic ethos. Papertôs formulation will be recognized, although Ilieva implemented her approach independently.

But difficulty arises in evaluating childrenôs work. If children produced work of cognitively higher quality than in the traditional classroom, the dismissive: ñThey used a computer!ò echoes down the school corridor. By using an assistive medium the children are perceived to be cheating. Here analogy with powered transport may be help: the children are being chided for lack of horsemanship when they are riding a train. The processes are not comparable, only the outcome. This suggests that the existing institutional infrastructure will inhibit rather than catalyze change. What is the alternative?

Private school, such as the one where Ilieva developed the curriculum is a possibility, but a decade or more on, national support notwithstanding, the effect on mainstream education is disappointing. The history of technology tells us that change comes slowly at first and accelerates when a) the technology is mature and b) conditions are favorable. Conditions become favorable if R&D is carried out in a way that facilitates application. An Ilieva now needs a setting where change-up from mastery of the medium to its application to the whole curriculum, including the new areas such as robotics, may be piloted.

Proposal. The Turing medium brings new possibilities. One of these is robotics. Primary school is the place to begin. Might it be possible, at EU level, to fund a set of primary school classes where teachers who understood both the medium and the children might develop new teaching method? Assistance from higher education would be valuable, particularly in matters technical. These classes would begin in the first grade and continue to the fourth. This offers a cycle of development throughout the primary school years. This suggests that the teacher would have a different role, teaching all grades to mastery and then developing application across the curriculum. This might also entail radical change in method in the core skills of literacy and numeracy. It would be an ongoing process, not a short term project.

Fig. 3. The contrast between biological complexity and technological simplicity. The forms of the LEGO elements and their colors, their animation with motors and lamps, and the aesthetic are all products of technicity. Like the children they are built from genomic information on properties of matter; but by cognitive rather than biological processes. The aesthetic aspect, the affective contribution of prefrontal cortex, signals healthy cognitive growth.

7 Conclusion

The technicity thesis simply puts together existing knowledge and comes to a new conclusion about what it is to be human. The only cognitively difficult aspect is the application of entropy. The children

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working with LEGO/Logo, figure 3, contrast the simplicity of technology with the complexity of biology. The V/T concept distinction is fundamental to education. A reviewer of a draft of this paper sought to contrast technological simplicity with biological "richness". The latter is a value-laden word, characteristic of V-conceptual thought. T-conceptual thinking linguistically contrasts 'simplicity with complexity. This distinction leads directly to the formal definition of entropy. The scientific conclusion is that the simple is the more powerful. But this is known: education starts from the simple and works to control of the complex. So did the child. So did evolution.

The Turing teaching notion is equally simple. The term was recently coined [12] as a linguistic means of redirecting attention from the hardware to the mind of the child. It replaces the V-conceptual term "technology" with a direct reference to the conceptual basis of a new medium available to education. The focus on medium directs attention to its relationship with the mind. This facilitates the critical analysis of existing media and their relationship to thought. The new capabilities of the medium will lead to curricular change: the introduction of robotics principles to six year-olds being an example. But the major changes will come in teaching method.

The square/diamond effect starkly demonstrates how fundamental the V/T concept distinction is. It contrasts animistic socio-perceptual thought, expressed in language, with that founded in technicity and tested against the properties of the real world. This is the difference between science and myth. It is the keystone of education. The V/T distinction is newly made in this paper and application to educational thinking will follow. In the physical sciences, it brought an end to speculation about perpetual motion. It is possible that education suffers from analogous false beliefs.

Surprising as it is, the second law of thermodynamics has as much to say about matters educational as it does about properties of matter. It prevents sensory information from being the foundation of technology and points towards the genome as the source of information of adequately low entropy. The question then becomes that of where and this information is expressed and how it is accessed by cognitive processes. The plausible mechanism of the original technicity concept had already provided an answer. It also identified affect, the aesthetic, as cognitively important. Educationally, the most important conclusion is the existence of two qualities of concept. This defines the role of education as giving children the tools to grasp the more powerful concepts constructed by the technicity adaptation – a true understanding of the earth revolving rather than the sun revolving around it; as opposed to a memorized verbalization. This can be assisted by the transition from Grammar schooling to Turing teaching – replacing text with Turing media. In this scenario, for which there are pressing economic as well as educational reasons, robotics becomes an integral part of the core curriculum as opposed to an isolated aspect of the STEM agenda. Transition to Turing teaching is prerequisite for progress.

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