Notes on the Basis for a Science of Construction: with remarks about primary school technology

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Abstract. In the context of educational robotics, the thesis that the highest cognitive capability of the human is technicity rather than speech is rehearsed and expanded to consider the role and maturation of prefrontal cortex. Children of primary age are undergoing a rapid process of prefrontal-cortical connection, most obviously in the affective and linguistic-social domain. Unremarked is the genesis of technicity, manifest in the core curricular activity of primary school. The cognitively superordinate role of technicity is explored thought literacy and numeracy. With this thinking as background, conditions under which robotics might successfully be embedded in primary school are considered. An example of successful practice is given, with a comment on programming medium.

Keywords: robotics, primary school, speech, technicity, science, evolution.

1 Introduction

Robotics in primary school has a history as long as the computer in the classroom. The basics: construction, mechanism, sensor and program were established then, and remain unchanged. But, robotics seems to need reintroducing with each generation. This may be because both ICT and its manifestation in robotics are óoptional extrasô in primary school. Teaching methods and media remain unchanged for the basics, literacy and numeracy. The presumption that language is our highest cognitive ability is unchallenged. In this situation óthe technologyô can not become embedded and must be fitted in. In this paper I continue my challenge to language, arguing that technicity is our highest evolved adaptation. This enables us to reconsider the computer, which like a brain operates in the time domain, as the medium of education. In so doing, we need to recognize that primary education is an exceedingly complex ecosystem and that the curriculum is a multidimensional matrix of interrelated and interacting parts. To add robotics as an isolated project is easy. To embed robotics requires reflection.

2 Background

At the beginning of educationõs adventure with the computer I was given a floor turtle to evaluate with my primary-school aged children. It was a simple dome that could be driven from a turtle graphics program called Dart, and it could beep. Having some

Proceedings of SIMPAR 2010 Workshops
Intl. Conf. on SIMULATION, MODELING and PROGRAMMING for AUTONOMOUS ROBOTS
Darmstadt (Germany) November 15-16, 2010
ISBN 978-3-00-032863-3
pp. 586-595

interest in cybernetics and having read Grey Walterôs [1] description of his ótortoiseô I was interested to try out this early classroom incarnation.

My children, who had language and spatial difficulties, were quickly bored with drawing shapes. Despite the authority given to ñTurtle Geometryò [2] and ñTurtle Talkò [3] and Papertôs notions of ówalking turtleô for a óbody syntonicô understanding of shape, I was very uneasy about introducing, unsupported, the 360 degrees of turn. The classroom floor being uneven, I used the turtle on a table where the children drove it around a village ï from which it fell when given an extra ó0ô in the óforwardô command, cracking the dome. This gave me the opportunity to modify it by flattening the dome and mounting degree scale and LEGO minifigure pointer on top (fig.1a).

Reflection on childrenôs love of animals and *Machina Speculatrix* led to the turtle I described at the first (1987) Eurologo conference (Fig.1b) and reprised at Eurologo 2007 [4]. It had light, sound, temperature, touch and direction (angle) sensors. All but the peripheral touch óskinô were built into LEGO Duplo bricks. The light sensor could detect color and the resistive plastic touch sensor knew where its óskinô had been touched. The direction sensor (360 degree potentiometer) fed turn information to the computer: a BBC Microcomputer with both analogue and user (parallel) ports used.

It is unlikely a primary school teacher could develop such a óturtleô using todayôs technology; and color sensing has only recently appeared on LEGOôs NXT 2.0.

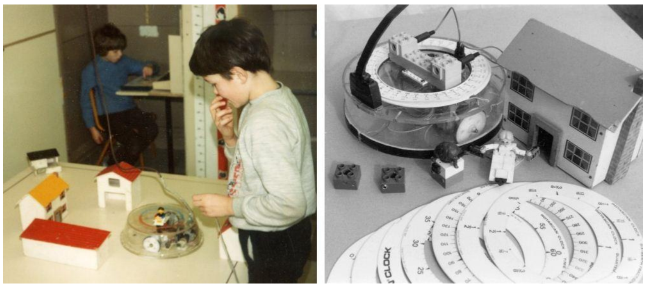

Fig. 1. Left: children in my class driving the 1984 topless turtle with protractor scale and LEGO pointer on top. Right the 1987 cybernetic manifestation presented at EuroLogo 1987.

All this was great fun, but in a primary school such activities are seen as very much secondary to the business of teaching basic skills ï reading, writing and arithmetic ï plus aspects of humanities, science and environment, usually situated in the context of a topic. Technology comes last with design. In primary school is often junk modeling ï plastic bottles, cartons, adhesive tape and paper-clips. If constructional materials, like LEGO, are used, the activity is seen as relaxing rather than taxing.

The WeDo product from the recently re-formed LEGO Education arm typifies the current approach to technology ï isolated models that demonstrate robotic principles, with suggestions for links to the wider curriculum and the STEM agenda.

Given that we are a highly technology dependent species, I have long considered the positioning of technology in school, primary school in particular, to be peculiar. My concern has been increased over recent years as the word ótechnologyô has drifted to denote only computer-based products. What, I asked myself, is technology? How is it that human beings, alone amongst animals can construct, in the Papertian [5] sense?

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3 Technicity

For a number of years I have explored the question of our technological capability. Surprised to discover that language is considered to be humanity's crowning cognitive capability and that there is no psychology of technology, I set out to challenge the former and try to provide a foundation for the latter – a science of construction. In this endeavor I took Heidegger's [6] notion of ‘technicity’ (the essence of technology) as a starting point and approached the question from a neo-Darwinian perspective. My ongoing research has been reported to EuroLogo [7],[8],[4] and other conferences including SIMPAR2008 [9] and Constructionism2010 [10]. Below is a summary.

3.1 Speech

I agree with the increasingly accepted view [11] that speech is a biological adaptation that evolved over the whole of human evolutionary history. I find the proposition that speech evolved to facilitate communication in an increasingly complex social milieu [12] to be compelling. The most persuasive argument is that the properties of speech are well evolved to maintain a reciprocally altruistic lifestyle in an evolutionary stable state [13][14]. With this development comes theory of mind (ToM) and awareness of self and others (intentionality) [15]. This complex of capabilities is prerequisite for the emergence of a capacity for technology because it facilitates teamwork and the trading of skills, capabilities and products as well as primary resources.

Thought. It is most unfortunate that the Russian word tęj ɥ in the title of Vigotsky's classic work [16] was translated as ‘language’ (Russian ʷʟʳ ʕtsɘʘʷ) when the word itself and Vigotsky's usage is ‘speech’, with all its connotations, in English. The idea that ‘internalized speech’ may be equated with thought is under increasing challenge. That we can have a conversation with ourselves as well as with others is not in doubt. This capability develops along with ToM. Given the role of the prefrontal cortex (see below) in creating “the future from the past”, the speech memory is as accessible for recombination as any other memory. I find myself in agreement with Pinker [17] when he argues that speech is one window on thought. I avoid the word ‘language’, which has been overused as a metaphor and thereby has inappropriate connotations.

3.2 Prefrontal cortex

One indisputable fact about human evolution is that brains got bigger. A bigger brain means more processing capacity; and greater differentiation and connectivity [18]. The modern human prefrontal cortex is (most probably) proportionally the largest that has ever evolved, though the Neanderthals had proportionately larger brains. Primates have the largest prefrontal cortices amongst mammals, with the great apes having the most. In chimpanzees the neocortex is about 17% prefrontal, in the human it is 29%. The role of the prefrontal cortex is executive. It organizes actions in the time domain, provides working memory, preparatory set, inhibitory attention. It actively acquires further executive memory and is “*for* the organization of behavior, reasoning and

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language.ò [19]. Prefrontal cortex is massively reciprocally connected to older parts of the brain (fig.2).

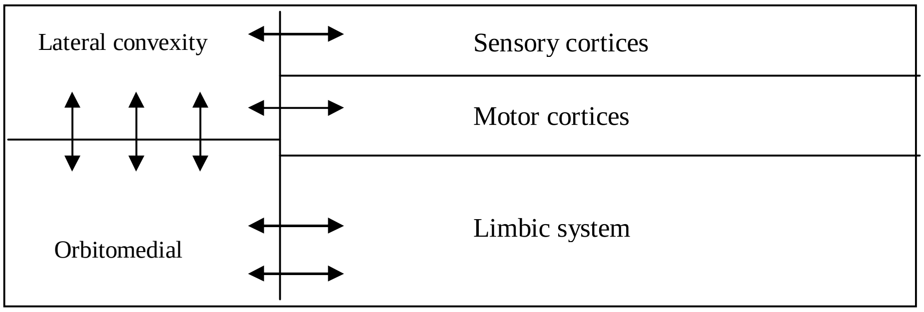

Fig. 2. Schematic of the major relationships of the prefrontal cortex to older parts of the brain.

Beautiful ideas. The prefrontal cortex has two major divisions: the orbitomedial and the lateral convexity. They are highly interconnected. The orbitomedial is of earlier evolutionary origin, matures by the end of the first decade of life and connects mostly to the limbic system where it modifies affect. It is essential for inhibitory control, motivation and execution of plans [20]. The lateral convexity is of more recent origin, matures later into the third decade of life and is cognitive in nature. It connects mostly to the sensory and motor cortices. It is the interaction between these two cortices that gives us the feeling that an idea or an artifact has beauty. It gives affect to cognition.

Immanent Data. The sources of data from which the prefrontal cortex can construct information are, in mammals and primates, the memory circuits of the neocortex. However, immanent in the structure of the nervous system is memory of the evolved function of neurons. By immanent, I mean data is built into the structure of the brain. Such immanent data is found in primary sensory cortex. Hubel [21] and others have located so-called feature detector neurons that react to specific elements of sensation. They include: pitch; the primary color pairs red/green, yellow/blue, dark/light; motion in a specific direction; lines of specific length and/or angle. A neuron that reacts to a horizontal line will not react at all to a vertical one. Those that react strongly to these orientations will react only weakly to oblique lines, for which there is another set of neurons. Were there to be prefrontal connection to neurons that embody this data then it would be available for prefrontal construction.

3.3 The technicity thesis

Human beings have a capacity for technology, technicity, because their big prefrontal cortex evolved connections to immanent data. This elemental data is used to create the unnaturally simple forms upon which component-built artifacts are based.

Evidence. The early signs of modern human behavior: points, geometric microliths, component built tools and use of color hint at an evolutionary change involving the connection of (lateral) prefrontal cortex to sources of immanent data. Early childhood educational toys embody elemental data found in primary auditory and visual cortex (fig.3).

Fig. 3. Examples of early childhood educational materiel illustrating their elemental character.

Perhaps more clearly, childrenôs drawing, a feverish activity that begins after speech has developed and continues to the end of the second decade of life, is also composed of elemental features: line and color. Children even attempt, in the execution, to build motion into the representation. Unfortunately for technicity research, the few works on children drawing are art oriented. Compare the sketch by an engineer with an early child ótadpoleô drawing (fig.4.). Does it not suggest a closer relationship to technology and geometry that with artistic expression?

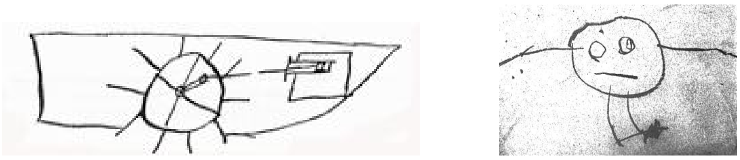

Fig. 4. An engineerôs sketch and a childôs ótadpoleô drawing compared to show their common elemental geometric character.

A final, and probably the most informative, example is a simple experiment with a square. Take a square in orientation (a) and ask a subject to name it. The answer will be ñsquare.ò Now show it in orientation (b). The answer will be ñdiamond.ò

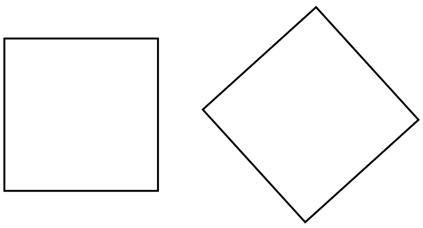

Fig. 5. Square/diamond: insight into our capacity for technology and its relationship to speech.

This experiment is critical because it accesses directly the behavior of feature detector neurons. The square shape triggers completely disjoint horizontal and vertical detector

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neurons. On rotation, the response from these neurons fades and that of the 45 degree oblique neurons strengthens. At a full one eighth turn the response from these neurons is at its maximum, and a different shape is perceived (and named as diamond). It takes a significant cognitive effort, as mathematics teachers will attest, to perceive the two as identical in form.

Taken with the other evidence, this experiment demonstrates the data source for our technology capacity: data immanent in the structure of the brain. It also throws a light upon the relationship between speech and technicity: speech provides a window onto our cognitive processes and, if analyzed with care, helps us to understand them.

Cognition. Our post-speciation technological and cultural trajectory, taken with these illustrations, tends strongly to support the basic thesis underlying technicity. They further suggest that technicity rather than ―languageǁ is our crowning cognitive capacity. In the light of prefrontal cortex development in the primary school years, this has significant implications for our perception of this phase of education.

4 School

Children arrive in primary school (aged five or six) with a language system that is virtually complete, but with vocabulary and range of conversation as yet limited. They are at the beginning of their interaction with technology. The development of their technicity capability is at the heart of any system of education for a species that has become dependent on technology. Language and cultural development have little need of a formal education system, both, including a second language, can be learned through day to day community interactions. However, for technology to progress, or not regress, a reliable generational learning system is needed. In less technologically complex societies this is achieved by the master-apprentice system, often within trade guilds or castes. In modern society, primary schooling in the first decade of life builds a foundation for secondary and tertiary education, extending into the third decade.

4.1 Primary education

The years of primary education, from six to ten, see the most rapid growth in prefrontal cortex connectivity. Orbitomedial (affective) prefrontal cortex is mostly mature by the end of this phase. Rapid connectivity growth for the lateral (cognitive) convexity also occurs in this phase, though it will continue throughout all phases of education. Primary education is the foundation for all that follows. It is essential that curriculum and teaching method are fully in tune with these neurological processes. Historically, this has not been a major concern of institutional education, particularly that provided by governments. Their concern has been to inculcate the perceived basic skills for life and learning: literacy and numeracy. In this they follow a tradition that has a six millennium history [22].

Cambridge Primary Review. In 2010 the results of the most wide ranging review of primary education in England ever undertaken was published by Alexander and his colleagues [23]. Alexander, in the best Vigotskian tradition, placed talking and social development at the heart of his conclusions. He had a major conceptual problem with computer technology (ICT), which he included in the Language domain in response to concerns about the Internet. Other aspects he relegated to science and technology. Alexanderõs conceptions of both language and technology, widely held in academic circles, are not in consistent with the technicity thesis. Let us consider and try to understand the primary school child from the new perspective I offer.

Primary schoolchildren. Throughout the primary phase of education the childõs prefrontal to older brain connections grow apace. The affective, motivational, social, attentional orbitomedial cortex and the cognitive lateral convexity both connect to their targets in the older parts of the brain. Both lay down new memories as a result of their environmental experience. The interconnection between the two prefrontal areas grows to integrate cognition and affect in a balanced individual.

Maturation and learning proceed faster for the affective domain. So, Alexander is right to call our attention to social and communication matters. But the foundations of cognitive competence are also established in this phase; and it is here that Alexander has failed ï not unreasonable given current conceptions. But he was correct to point out that the primary school child is at his or her best when learning is situate, as in the English primary school ótopicô and not when isolated knowledge or skills are taught. Good primary teaching revolves round learning based on a óstoryô where the childõs well developed language skills may be brought to bear on the cognitively unfamiliar. In talking, the teacher and the child amongst children can use the window of language to look at thought. They can situate their learning in a social context supportive of our reciprocally altruistic lifestyle and develop a capacity for teamwork. But this talk is a tool for exercising and developing competence in their (little noticed) technicity.

Rote and discursive learning vs construction. All learning needs a good memory. Evolution has equipped us to remember what we hear and what we say. But speech evolved before technicity and is disjoint from it. It does, however, provide an indirect window on cognition in the latter, species unique domain. It follows that the capacity to talk and write about what is learned offers a quick and easy means of determining a childõs state of knowledge ï indirectly. Question and answer is open to abuse: a child, or adult, can memorize the required verbal response independently of any learning. Herein lie the problems of both rote and discursive approaches to teaching. Therefore, all teaching needs to be constructive. Verbal assessment may be used, but with great caution. Let us consider the basics ï literacy and numeracy ï from the perspective of speech and technicity as disjoint capabilities.

Reading, writing and arithmetic. It should by now be obvious that these basic skills are technological. Systems of writing use elemental shape features to provide a script that minimizes the effects of the brainõs object constancy system. This means that letters, like the ósquare-diamondô will be easily discriminated. (It breaks down with pdpq and 69.) This technology is then used to note essential, abstracted, features of speech, including number relationships.

Writing records only certain aspects of speech: the digital and segmental words and grammar. The child must learn to abstract this information, and to discard all prosodic

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and personal information, in order to map sound to graphemes. From the perspective of the technology, the notion that writing should represent the sounds of spoken language is unsound. The engineers who develop computer speech systems know this well because they have to add artificial prosody to make speech derived from text sound natural. Heretofore literacy teaching has taken speech as the referent. Computer technology can reverse this. By not adding ersatz naturalism to text to speech systems, children might be offered a model of what writing sounds like ï a technique used by many with spelling difficulties to memorize letter sequences.

Arithmetic notation is more clearly a technology. In Europe we retain the Roman numerals some purposes. This technology is unsuited to (mental) computation, which must be carried out physically on an abacus. The modern, Hindu-Arabic place-value notation, conversely, is well suited to pencil and paper (external memory assisted) computation. It matches our mental processes better. Spoken numbers work the same way as the numeral system. We enumerate to nine with distinct words then, on the count of ten, bundle-up into a single entity. We then count teens, twenties, and so on. This is in accord with Millers ñMagic Number 7±2ò for memorization capacity. The window our speech opened onto our thinking made possible the development of a technology matched it. We may speculate to what extent school structural materials that match physical counting, e.g. Dienes blocks and hundred-squares, interfere with childrenôs arithmetic learning; and if using a calculator really would rot their brains.

5 Robotics in Primary School

Learning to think with technology is the core of primary schooling. Therefore robotics need not be perceived as exotic or esoteric. Learning to construct a mechanism and write a program to make it perform a desired action is not fundamentally different from learning to read and write. The same principles apply. To become literate and numerate children must read, write and do sums alone, independently, for themselves. They combine the basic components ï letters and numerals ï in a construction that expresses their thought. The aim of robotics should be to give children the capability to construct an entity from basic components: as they do when they write. This implies that making isolated models by following a set of instructions using supplied parts (cf. self-assembly furniture) is, like copy-writing, an exercise in technique not thought. Robotic construction, unlike the basics, may best be carried out in a team, if only for financial reasons. This opens up the question of teaching method ï how to learn individually and construct communally. Working together is a learned skill.

Very great care needs to be taken to ensure that this area of study is not isolated from the other activities for children of this age. Integration with the curriculum by itself is not adequate. Robotics needs to use the childrenôs learning as they progress in school. An ICT curriculum that enables children systematically and progressively to develop skills with mouse, keyboard and the full range of computer possibilities from age five to ten plus would naturally include robotics. To be viable, teaching method needs to be cost-effective. To be effective, robotics work is best situated in a scenario that the children understand from real life. Ideally robotics would be embedded in a multi-subject topic, an approach of the sort favored in primary schools in England.

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5.1 Situating robotics

Children in primary school are in classes of twenty or more, except in private schools. A computer room with 12 or so machines makes possible the LEGO WeDo approach: a class set of 15 kits (ú1.500). Although LEGO provides instructions for 12 models with curriculum links, this is an isolated, perhaps one-year, ICT activity. I cite LEGO because the system has great constructional possibilities. Many schools have a little LEGO because the children find it attractive and like to build models as a relaxation from the essentials of schooling: language and mathematics. The technicity thesis, contrarily, insists that such construction is also an essential and requires systematic teaching. Robotics, computer controlled constructions, fit naturally into this. LEGO has provided material, from Interface A onwards, to facilitate it. All except the NXT integrate well with the original brick. For a quarter century there has been the option of sustainable constructional robotics. Only understanding was necessary.

Few primary school teachers have understood. A few, in supportive circumstances, have developed sustainable curricula and teaching methods. Ilieva [24][25] describes her approach, using LEGO Dacta Control Lab, within a national ICT curriculum [26]. The youngest children learn to construct with LEGO and to work with the computer separately. These skills are joined in projects that control external elements: robotics. Always there is a situation with a story. The story creates the programming algorithm. The children, as a team, build the situation and write the program. Thus, the program is situated and understandable, as are mistakes. Demands on the children, cognitive and constructional, increase as sensors are introduced through classes one to four.

Programming environment. This question, how best to write for the computer, has a deep history and goes to the heart of ICT teaching in primary school. Primary school children are learning to read, write and do arithmetic. Icon and block based software certainly makes programming easier on the instant and text-based Logo is harder to learn. But, Logo does help children to rehearse the skills they are developing by using the old technology of writing. It helps integrate the programming of robots with core skills taught in school and builds one more bridge between language and technology.

6 Concluding Remarks

In this and previous papers I have attempted to describe what I consider an inhibiting factor in the development of a constructionist approach to education: a major hole in our knowledge of ourselves. Speech and a good memory are the basis of rote learning, easy to assess and still widely practiced. A scientific understanding of our capacity for technology is prerequisite before we can lay a post-philosophical foundation for a constructional pedagogy. With such a foundation we can identify the ótechnologiesô underpinning primary schooling. This makes teaching method open to an engineering mode of scrutiny. As my opening paragraph demonstrates, robotics has been around in primary school intermittently over many years. Yesterdayôs exemplary practice may well be valid today. After all, turning a motor on and off and acting on the input from a sensor are no different today than they were 25 years ago. The problem then,

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as now, is how to build the type of activity that we call robotics sustainably into the primary ecology. The technicity thesis provides a rationale for making the effort.

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