

Primary Robotics: Laying Sound Foundations

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Abstract

Robotics has recently reappeared in primary education under the banner of curriculum enhancement. Some thirty years ago it made a brief appearance as control technology and in some approaches to the Logo floor and screen turtle. A more descriptive term would be 'controlling external devices' where these included motors, lights and sensors. Like computer programming, such activities are seen as the prerogative of late and post-primary education: an interface to secondary school. In a computer-rich culture, connected or otherwise, this is not satisfactory. Capability to construct, be it with letters or material, is intrinsic to primary education from the outset. Practice that introduces the foundations of robotics in the foundation stage of education is described. Its rationale is elaborated in the context both of the computer as a new medium. This is informed by some recent proposals about the nature of technology and their implication for primary education.

Keywords

robotics, primary school, technicity, curriculum, pedagogy, language, programming

INTRODUCTION

The words used to describe educational practice and curricula shift around but what we actually teach remains largely the same. First there was cybernetics, then control technology, now robotics. For children, it comes down to making models, ones that react to what they do or say, during the four years of primary school. For teachers, there is the problem of ever changing kit (and its quality), the second class status of technology and an aversion to 'programming' in traditionalist educational thought. (Such educators, influenced by Vigotsky (1962), believe they teach effective use of language (Alexander 2010). This follows from a cultural presumption that language is the crowning intellectual achievement of the human race). Mathematics and language have a curriculum that focuses on continuous cognitive development: miss a maths lesson and there is a gap in your knowledge. Robotics is treated as a dip-in (Arlegui et al 2011) or taster (Janošcová 2010) subject: enrichment activities rather than the mainstream. Some considered it to be intellectually undemanding; to be studied by the academically challenged. There is a rag-bag of presumptions that informs this viewpoint that need urgently to be challenged. We split this paper into two parts. The first, largely authored by Doyle will deal with the theoretical issues. The second, contributed by Ilieva, describes successful practice developed over a twenty year period, in the face of active professional apathy. LEGO is the material of choice. This has advantages and disadvantages. The longevity of bricks makes the economics acceptable, but the initial costs are high. Many children also have LEGO at home and so 'homework' is a possibility (as is the donation of used LEGO

to school). But LEGO is a toy company and its products are highly media-influenced. This has an impact on children's perception of what design and technology through LEGO might be. There is also the issue of component availability; highly dependent on sets on the market. This has been to some extent ameliorated by internet supply from both official and unofficial LEGO sources, for example, the BrickLink network. Teaching with LEGO can be frustrating at times but, on balance, there is no better material. Logo is its complement. Children at the beginning of literacy and numeracy need as many opportunities as possible to apply their emerging skills and text-based Logo, systematically used and situated in child language, is an ideal medium.

The intellectual status of technology

The mind of a child from infancy to puberty develops and changes at a breathtaking pace. This process is poorly understood. Fuster (2008) remarked, in his standard text on prefrontal cortex, that Jean Piaget was the only psychologist really to study child development. Prefrontal cortex is now known to be the executive of the mind and the site of its working memory. It is massively interconnected with the rest of the brain, from which it gathers information, processes it and within which it stores the product. The primary school years see this connectivity mature. How it connects up is highly influenced by experience. This makes primary school the most intellectually complex educational phase. In the face of the language development presumption (Vigotsky 1962) and a utilitarian curriculum against which teacher and child are assessed, primary school teachers show remarkable insight into the cognitive and affective development of their charges. Classroom walls are covered with products of pencil and paper, or the computer printer. If language is primary, why is graphic expression so highly regarded?

To answer this question, Ó Dúill (2010, 2012) set out to provide a basis for Papert's (1991) intuition that 'making an object open to public inspection' is somehow more "felicitous" for learning than is verbal instruction. Ó Dúill proposed that the capacity to make such objects means that the human has a biological adaptation possessed by no other species, past or present. He called this the technicity adaptation as it is the source of the human capacity for technology. Given that his proposition is not widely known, it is summarised below:

Technology is an order of magnitude more simple than nature: a carpenter's pincer is less complex in material and form than that of a crab, though both perform the same function. By the third law of thermodynamics, simplicity is equal to lower entropy (in both Clausian and Shannon senses). Lower relative entropy implies a greater capacity to do work, physical or intellectual. The greater capacity for thought follows from the definition of a Turing machine. Turing described a machine that scanned a tape marked with symbols. The read/write head would write, erase, and move back and forth according to its table of instructions and current machine state. (The model was Turing himself with his notebook, pencil/eraser, and state of mind.) A machine needs energy input to do work. This implies an entropy differential. The only entropy differential in nature, other than physical forces, is that between genes and the phenotype they specify. (A body is far more complex than its genome). The conundrum of technology is how to generate simplicity from natural complexity.

The clue is in our concept of colour. We perceive a colour circle in which blue and red join to make purple. Most animals, since the bony fishes evolved some five hundred million years ago, have this type of colour vision. Thus, it is very ancient genetic information. However, the rainbow has no purple. The source of purple is a neural mechanism described by Hubel (1995) and colleagues. We have a concept of pure colour; and this puzzled the Platonists. It is obvious that, although our pet goldfish can perceive purple, it has no concept of purple: concepts are a function of the mammalian neocortex, which is most highly developed in the human. For a con-

cept of purple to be possible it is necessary for unassociated colour information to reach the prefrontal area. This can occur only if a direct link from prefrontal cortex to Hubel neurones exists. Ó Dúill proposed that in the human this link evolved. This is consistent with the nature and trajectory of brain expansion in the human.

The proposed 'technicity link' connects Hubel zone to cognition. It is consistent with the neural colour mechanism which generates a colour space based on the primary opponents red/ green, blue/yellow, and black/white. Other information in the Hubel zone includes line length and angle, and direction of motion. These are the base of geometry and mechanics. Papertian objects, e.g. a square, and natural concepts, e.g. 'goldfish,' are both created from the same basic components. The former are the more powerful because they not derived from natural sense data but created de-novo by the mind. Technology is intellectually more powerful than language. Here is the source of the power of scientific thought.

Ó Dúill (2012) proceeded to demonstrate that the human has available two qualities of thought; and that they conflict.

- V-concepts originate from perceptual processes and are expressible verbally. They are tested for perceptual plausibility, linguistic consistency and social acceptability.
- T-concepts are built from raw Hubel information and expressed non-verbally. They are proven against the behaviour of the physical world.

Science uses low entropy t-concepts to correct misconceived v-concepts, a process described in Bransford et al (2000).

Primary minds

We are now in a better position to understand child development in primary school. Language, a prior evolutionary adaptation, is already available. Technicity is in the process of coming on stream. Its first manifestation is the scribbles that children invest with meaning – expressing something clearly in mind that they as yet have no effective output channel for (Gardner 1980, Anning & Ring 2004); see also Bloom (1993) on child language development. The first tadpole drawings are composed from line and angle information and represent significant features in the manner of a naïve engineering drawing. This non-verbal communication, which is not art, is soon co-opted to represent the cognitive aspect of language (literacy) and to look through the window language opens onto the mind in place-value numeral arithmetic. Motion is developed in the trajectories of letter, numeral and shape formation. Prefrontal maturation is co-terminal with this phase of education, the experience which sculpts it. The traditional emphasis on pencil and paper cripples the capability to think in three dimensions and constrains use of the mathematics learned.

Rethinking primary robotics

Robotics has two components: construction and programming. The latter is easier to deal with. Text-based programming uses exactly the same symbols that children are learning and provides an additional means of applying them. Thus, programming in Logo is appropriate from the first grade – providing the context is meaningful to the children. For instance > and < have been learned in kindergarten and may be applied to a light sensor. Construction is cognitively more complex. Transfer of skills from art lessons where paper provides a stable substrate does not make for stable constructions: learning to 'see' in three dimensions takes time. Early constructions reflect the imaginative but disjointed character of their drawings. Thus, the emphasis in the initial stage must be on the development of individual capability to conceive and construct sound, stable, and pleasing structures. Both authors have taught with LEGO and Logo in primary school for a quarter century or more. Ilieva has always seen their combination as integral to primary teaching, an approach described below. Before this we offer a short historical excursion.

The history of robotics in education has been one of a bolt-on addition. This is nicely traced through LEGO Company products. LEGO Logo, in the tradition of intervention by computer scientists in education that continues (Furber 2012), was designed for the primary/secondary interface. The first products were related to the real world and controlled using Logo. After text-based programming in primary school was banned by educational traditionalists, children had no skills to deploy. The solution was to use pictographic programming. LEGO left Logo for an alliance with National Instruments and their professional engineering product LabVIEW. Primary schools received the pictographic WeDo software. The link between writing and robotics was severed. But from the outset, computer language was ambiguous. Did the 'reverse direction' command apply to the motor or the current? In primary school we teach children about electricity: 'reverse polarity' would not have been ambiguous and could be related to the simple circuits we teach children about. Rendered 'motor this way' 'motor that way' as in Scratch and WeDo, the pedagogical balance has come down on the side of percept: non-scientific v-conceptual thinking. For Logo, it was easy to clarify the real referent by redefining the 'rd' command as 'reverse polarity' thus linking to science: t-conceptual thinking: not possible with Scratch and WeDo. At present children bring neither prerequisite constructional nor programming skills to a project, resulting use need of ready-made kits and simplistic programming. The links to the wider curriculum exist only in vague cross-referencing, not in the application of parallel learning. It is not too harsh a judgement to assert that robotics has regressed since its introduction with the LEGO Interface A and LEGO TC Logo in the later 1980s.

Model curriculum

Ilieva (Ilieva & Ivailov 1999) at the turn of the millennium began to resolve this issue by integrating the control of external objects into the primary school ICT curriculum. This was incorporated in the first Bulgarian national curriculum for ICT, and remains available as an elective option. Progress was reported some ten years later (Ilieva 2010). Her practice is described in Table 1. Mastering the computer as a medium, programming, and construction are learned in concert.

The principle on which the teaching is based is that robotics is not an experiment or a means of attracting children to science and technology. It needs to be and it can be a long-term, organised and systematic process of teaching throughout primary school. Robotics is introduced to give children a realistic understanding of robotics in an appropriate manner for the developing mind of a primary school child. Learning is situated in contexts that are meaningful for children and based in the real world. Where possible, learning is related to the other school disciplines. Robotics makes it possible to organize a new educative environment in the school and to transform learning from individual activity into teamwork.

Models are not built as isolates but as part of a situation, ensuring the addressing of the aesthetic as well as the technical. In thinking over the prototypes it is necessary to bear in mind two things:

- a) the complexity of the structure into which the computer-controlled element is going to be integrated, and
- b) the complexity of the guidelines to be followed for its implementation.

Thus, models are created that:

- Can be implemented by the children as a construction task with their available skills and materials;
- Naturally presume the presence of controllable devices – motors, lamps, sound elements, sensors;
- Will be attractive in both appearance and "behaviour";
- Recreate objects familiar and interesting to the children;
- Recreate "behaviour" that could be met in real life, and that is simple and clear enough to be described and then programmed.

Table 1: Programme of study outline for the ICT robotics curriculum developed by Ilieva

	ICT	LEGO	TEAMWORK
1st grade	Introducing the computer. Learning to use the mouse. Working with graphics and sound. Using ToolKid, specially designed software.	Get to know the construction material. Make the first simple models. Using LEGO bricks.	Individual work to a teacher example. Individual work on their own idea. First steps to learn to work in a team of two. Outcome: individual projects
2nd grade	Learning to use the keyboard. Working with graphics, text, animation, sound and combinations of these. Using ToolKid.	Make a variety of more difficult constructions. Make more realistic models with many details. Learn to recreate a first simple situation. Introducing controllable models and programming.	Working individually or in twos or threes on one common theme discussed with and agreed by all children. Every construction part of the common project. No isolated models allowed. Outcome: class project.
3rd grade	Individual and class projects that combine different types of information. Using ToolKid, MS Word and Paint and the Internet. Product: movies, stories, comics, slide-show.	First robotics projects using sensors. Programming with procedures. Modelling more complex situations.	Freedom to choose and change team membership in the context of each new class project. Learn to cooperate with the work of the younger children on school projects.
4th grade	Use of the Internet, Paint. Word and PowerPoint to make individual and class projects based on the curriculum for other school subjects.	Larger and more complex robotics projects. Programming with super-procedures and conditions.	Coordinate the work of all classes on whole school projects. Organise a presentation, introducing the work of all children, to the school and parents.

The task is never reduced to the mere making of an isolated controllable model. It is always an element of a situation reproducing as closely and realistically as possible the object's natural environment and its functioning within it.

- The situation around the controllable model and its interlacing with other surrounding objects as it is in real life makes its "behaviour" more authentic and more understandable.
- This helps the children to see more clearly the algorithm of functioning of the model and comprehend its purpose. In turn, this gives more sense to programming and reduces the degree of its abstraction.
- The design of situations is more motivating, more challenging and more creative than the mere creation of an isolated prototype. It is richer in correlations, interactions and dependencies which should be sought, identified and recreated deliberately; which implies better cognition.
- The modelling of situations is conducive to the organization of team-work. The objects are numerous but they are all elements of a large comprehensive project. Every child participates actively in creation, making his/her individual contribution. Another advantage is that there could be more than one controllable object which makes programming richer, more sophisticated and more open to variation.

It will be seen that the allegedly exciting and motivating mobile robots are absent. Static models and simple programs are the norm, although a vehicle may be incorporated if appropriate in the situation. An example is the “police action” project shown in Figure 1 and Table 2. It will be seen from these that the latest products are not used. Control Lab, from 1995 running on a pre Windows XP operating system (Win 95 to Millennium), has more to offer in terms of programmable elements than does WeDo and the Logo programming environment facilitates links to the literacy and numeracy curriculum that are not possible in LabVIEW based environments.

Table 2: The situation and story for “police action” and its translation into a Logo program.

STORY - SITUATION	PROGRAM
The story is based on how to keep your house safe from burglars when you are not at home.	to car talkto "motorc setpower 5 onfor 14 end
To make the house safe we need a security system. This is in two parts. First we need a sensor to react when the house is broken into. Second, we need an alarm connected to the police station. The alarms in houses detect movement. We do not have one of these, so we use a light sensor that reacts when the house is broken into. The light sensor is installed during the construction of the house. It reacts when the doors or windows are opened and light enters. The sensor is connected to an alarm in the police station. The alarm sounds for one and a half minutes. At the end of this time the policemen react and drive quickly to the house in the police car.	to policecar talkto "motora setpower 7 onfor 12 end
The children write the story of a burglary in a program. They write a procedure car for the car of the “bad people” who come to rob the house. They write a procedure alarm that connects the working of the sensor with the working of the alarm. They write a procedure policecar that controls the movement of the police car so that it goes exactly to the house. The superprocedure police controls all of the action.	to alarm talkto "soundb waituntil [light5 > 35] onfor 40 rd onfor 50 end
The children need only to open the windows and doors when the “bad people” try to get into the house.	to police car alarm policecar end

Note how the ‘rd’ command in the “alarm” procedure may be explained in relation to the flow of current between positive and negative terminals of a battery.

Small children small robots

This contrasts with using robots in school. From BigTrak in 1979 (Anderson 1986) to BeeBot, programmable toys have been used in primary schools. They are not seen as an entrée to robotics (Catlin et al 2012, Petrovic 2012). The English national curriculum does not commend them for science and technology but there remains a mention in Mathematics E14 (QCA 2010), a remnant of turtle graphics.

SUMMARY

Both the theory and practice discussed have been developed by practising primary school teachers with deep understanding of child development. The former supports Papert’s intuition that construction is intellectually more powerful than language. The latter emphasises the importance, for primary school, of robotics not being a splinter activity but rather serving the whole curriculum, including literacy and mathematics.



Figure 1: The model for “police action” showing interface and software.

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Biographies



Mike Doyle is a primary school teacher who has had a long involvement with computers in school. He is former Chair of the British Logo User Group and a founder of the EuroLogo series of conferences (now Constructionism). As an ICT and technology coordinator with a psychology background, he has an interest in the human capacity for technology. A former local politician and school governor, he has observed the difficulty educationalists have with ICT. He teaches design & technology using LEGO.



Vessela Ilieva is a primary school teacher in Sofia, Bulgaria. With a colleague she wrote the first Bulgarian primary school national curriculum in IT and was part of the team that wrote the second. She authored teacher's and children's books in support of them. She remains a primary school teacher committed to creativity in ICT. To this end she teaches teachers to teach ICT in this way. She is working in her school with LEGO construction and robotics with children from first to fourth grade as well.

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