Tangible Programming Elements for Young Children

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ABSTRACT
Tangible programming elements offer the dynamic and programmable properties of a computer without the complexity introduced by the keyboard, mouse and screen. This paper explores the extent to which programming skills are used by children during interactions with a set of tangible programming elements: the Electronic Blocks. An evaluation of the Electronic Blocks indicates that children become heavily engaged with the blocks, and learn simple programming with a minimum of adult support.

Keywords
Education, programming, children, tangible interface

INTRODUCTION
Electronic Blocks are tangible programming elements – blocks with electronic circuits inside them that can be stacked and arranged to form structures that interact with the physical world. By placing Electronic Blocks on top of one another, young children build "computer programs" where each stack of Electronic Blocks is capable of a different function. Using the blocks, children are able to create robots that crash into each other, lights that flash when you clap, and animals that chirp at each other.

Electronic Block research has two key objectives: (a) to produce a *developmentally appropriate resource* for use by children under eight year of age (based on [1]); and (b) to create a resource that has the *dynamic programmable properties* of a computer (following ideas from [2] and [3]). This paper outlines the design of the electronic blocks and describes an evaluation that determines the extent to which the Electronic Blocks meet these two objectives.

ELECTRONIC BLOCKS
The Electronic Blocks have been designed so children can connect them just as they would any other building blocks. The dynamic and intelligent properties of the blocks have been created by placing electronics inside Lego Duplo Primo™ blocks. This ensures that the blocks are easy to stack and connect. There are no external wires or connectors that children are required to attach and there is no need to use any conventional computing resources. Sensors and effectors built into the blocks allow children to create structures that interact with the environment. The blocks have inputs and outputs and when stacked, the output of one block controls the input of another.

There are three kinds of Electronic Blocks: *sensor* blocks, *action* blocks and *logic* blocks. The sensor blocks detect *light*, *sound* and *touch* while the action blocks are capable of producing *light*, *sound* and *movement*. By connecting sensor blocks with action blocks children can program their own structures (see Figure 1). The inclusion of logic blocks – blocks that logically *negate*, *and*, *delay*, and *toggle* signals between blocks – adds an additional dimension to the capabilities of the children's creations.

Figure 1: A touch block attached to a light block will cause the light to turn on whenever sensor plate is touched.

EVALUATION OF ELECTRONIC BLOCKS
The evaluation of Electronic Blocks took place at an on-campus university preschool and at a suburban primary school with 40 children aged between 4 and 8 years. Twelve experimental sessions spanning four weeks were conducted.

Evaluation of Developmental Appropriateness
Levels of Attention and Interest
Over the period of the evaluation, most children exhibited high levels of attention and demonstrated an interest in the Electronic Blocks. For the preschoolers, the level of interest was manifested in the amount of time spent with the blocks, with them averaging approximately 30 minutes over the evaluation period. School aged children exhibited high

attention levels through their persistence, intensity of thought, and commitment to creating Electronic Blocks structures without assistance. A majority of children found the blocks enjoyable to use, as demonstrated by positive body language, an expressed eagerness to "play" with the blocks and responses to construction challenges.

Understanding of the Electronic Blocks' Functionality

All of the children who built with the blocks gained a sound understanding of sensor and action blocks. While all school age children gained an understanding of the functionality of the all logic blocks, the younger children most easily comprehended the ways in which *not* blocks and *toggle* blocks could be used in Electronic Block constructions. The younger children struggled to see how more complex and useful systems could be developed with the *and* block and the *delay* block. They had difficulty grasping the relationship between the invisible signals passed between blocks and the behaviours of the logic elements.

Frustration Levels

Very few children exhibited signs of frustration while using the blocks. Most commonly frustration was exhibited when Electronic Block stacks did not produce the desired or expected outcome. One notable episode occurred on the first day of the evaluation. Outgoing *R* created a sound activated car and in the process stated exuberantly "I love these". A few minutes later, failure to get a remote control car working elicited the response "I hate these". One could argue that this is a "typical" response to technology when it works the way we want it to, and then when it doesn't!

In summary, the Electronic Blocks are developmentally appropriate for children as young as four. This is supported by the high level of enjoyment and engagement in the block construction tasks, and the demonstrated understanding of the blocks' functionality.

Evaluation of Programmability

Understanding Syntax

The physical affordances of the Electronic Blocks enforce the simple syntax. The children were unable to create stacks where the function was undefined or ambiguous. This does not imply that all program stacks produced the desired or even useful behaviour, only that the blocks stacks were syntactically correct. Because of the use of physical affordances in an everyday play tool (blocks) the syntax required no explanation, and was immediately understood. The blocks have no buttons to press or rituals to perform to make them work; they simply embody their function.

Coding Simple Structures

A large majority of the construction occurring during the evaluation resulted in working program stacks. While the younger children did not always understand how their constructions worked, particularly when build with logic blocks, the children generated enthusiastic responses when their constructions produced some behaviour. Older children were able to create Electronic Block stacks to achieve a desired result. They generally found it easy to identify the appropriate sensor and action blocks for specific tasks. When using logic blocks, older children mainly used trial and error techniques to produce desired behaviours.

Debugging Program Stacks

The design of the Electronic Blocks easily allows children to see when an expected behaviour is not produced, but the cause of the bug is not always readily apparent. Examples of young children debugging their Electronic Block stacks were limited by a lack of understanding about the nature of interactions between blocks. Older children successfully debugged code stacks, as their obviously deeper understanding of the blocks allowed them to alter structures to produce the behaviours they desired.

Reuse of "Code" Fragments

It was exciting to see many of examples of code re-use. During the initial sessions children would remove working sensor-logic combinations from structures that the investigator had used to demonstrate concepts, and create new structures.

In summary, children who became engaged with the Electronic Blocks were able to perform programming tasks. The physical nature of the blocks effectively enforced a readily understood syntax. Programming ability was demonstrated by the construction of working stacks, the ability to debug non-working stacks, and the re-use of "code" fragments.

CONCLUSION

Electronic Blocks open the world of programming to the very young in a way that is at once engaging and developmentally appropriate. The key to their accessibility is a tangible interface that shares its physical basis with common childhood experience. Electronic Blocks, and the many levels of programming that they facilitate, strengthen the role of children as competent designers and creators of technology.

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