Using Developmental Theories to Inform the Design of Technology for Children

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ABSTRACT
Electronic Blocks are a new programming environment, designed specifically for children aged between three and eight years. As such, the design of the Electronic Block environment is firmly based on principles of developmentally appropriate practices in early childhood education. The Electronic Blocks are physical, stackable blocks that include sensor blocks, action blocks and logic blocks. Evaluation of the Electronic Blocks with both preschool and primary school children shows that the blocks' ease of use and power of engagement have created a compelling tool for the introduction of meaningful technology education in an early childhood setting. The key to the effectiveness of the Electronic Blocks lies in an adherence to theories of development and learning throughout the Electronic Blocks design process.

Keywords
Children, tangible interfaces, design, developmental psychology, educational applications

INTRODUCTION
This paper concerns the development of a new educational resource for early childhood technology education. The development has involved a detailed analysis of the target audience, the formulation of appropriate design criteria, the construction of the resource and its subsequent evaluation.

The end product has been labeled "Electronic Blocks". Electronic Blocks are blocks – much like children's building blocks – with electronic circuits inside them. They have inputs and outputs and, when connected, the output of one block controls the input of another. They aim to facilitate the development of technological capability through enabling young children aged between three and eight to design, construct, explore and evaluate dynamic systems.

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Electronic Blocks have been designed and built to provide a *developmentally appropriate* means through which young children are able to experience the programmable and dynamic properties of a computer. Specifically they are an educational technology designed to provide young children, aged between three and eight years of age, with opportunities to explore technology in a *purposeful* and *appropriate* way. A large body of child development literature has been studied and consequently utilized in the design of the Electronic Blocks to ensure that this aim is achieved.

The key lesson from the design process was the importance of utilizing research from the field of developmental psychology. While there are many methods we can employ to guide the design of suitable technology for young children from participatory design techniques to more traditional iterative design processes [for an overview see 4], drawing on a knowledge-base developed over the past 50 years in developmental psychology has been invaluable in the design process. By grounding design in what is known about how children think and learn designers of technology for young children are able to utilize a long tradition of well established guidelines. The development of the Electronic Blocks is an example of how this strategy can be successfully incorporated into the design process.

BACKGROUND
Developmentally appropriate practice is recognized as the guiding concept behind high quality early childhood education [2]. It is advocated by early childhood professionals to ensure that young children's learning experiences are age appropriate, individually appropriate and culturally appropriate. As Hitz [6] outlines, there are two basic assumptions underlying developmentally appropriate practices.

1. Young children have somewhat different physical, social, emotional, and learning needs than older children and adults.
2. There are individual differences that should impact on teaching practices. Same-age children vary widely in

their rate of development, interests, aptitudes, temperament, and experiences.

Consequently, it is important that the design of technology for young children considers the nature of young children and how they learn.

Based on the early childhood development and learning literature, technology developed for young children under the age of eight should understand that these children are pre-operational, they rely more on their visual and auditory perception for knowledge [1, 9]. Children are active learners, drawing on direct physical and social experience to construct their own understandings of the world around them [1, 8]. Piaget, a central figure in the field of cognitive developmental theory, developed a theory of constructivism which proposes the idea that children construct their own understanding through interaction with their environment [7, 8]. The most important consideration is that children learn by doing and that they best construct knowledge in an environment that allows opportunities to explore and play [5, 10].

In developing a new resource it must be remembered that young children are sensory dependent; that abstract thought and intangibles beyond their immediate world are vague and unreal [9]. Knowledge for young children is largely learned through first hand experience with objects [2]. The fundamental implication for resource development is that children need something they can see, touch, hear and feel. It must make provisions for children who learn by directly interacting with their world.

A new resource for technology education needs to consider children as individuals, with individual interests and backgrounds, with differences in skill and ability levels. Therefore, flexibility and extensibility are important attributes of the any new technology for young children. Such flexibility allows children to work independently fosters a sense of autonomy and self-control while offering opportunities to practice newly acquired skills and providing challenges just beyond the level of children's present mastery [2].

Opportunities to discover, be creative and solve problems are also important. Cognitive development benefits greatly from children's involvement in creative thinking and problem solving activities [2, 3]. Research has found that children who are encouraged to find and 'play' with problems learn important problem solving skills and are subsequently better equipped to cope with real-life problems [10].

Design Criteria Based on Theories of Development and Learning

Six design criteria for the Electronic Blocks have stemmed from this understanding of early childhood development and learning. The fundamental design criteria are:

1. Activities are open-ended and discovery-oriented, allowing children to be actively involved in learning process;
2. Interaction encourages child-initiated play;
3. Experiences involve active manipulation and transformation of real materials;
4. Entry level knowledge and experience is kept to a minimum;
5. Provision is made for children's varied skill and ability levels;
6. Construction activities that involve design, creation and evaluation processes form the basis of interactions;

These six design criteria form the platform on which the Electronic Blocks have been designed. They specifically address the aim of creating of a developmentally appropriate resource.

ELECTRONIC BLOCK DESIGN

Electronic Blocks are physical building blocks. The Electronic Blocks have been made by placing electronics inside LEGO® Duplo™ Primo™ blocks. As such they meet design criterion three: experiences involve active manipulation and transformation of real materials. Electronic Blocks utilize valuable properties of everyday building of blocks. They have been designed so children can connect them just as they would any other blocks. Electronic Blocks are physically embodied and consequently provide experiences that involve active manipulation and transformational of real materials. They are a resource that children can carry, stack and balance.

This "physicality" of the resource also ensures that design criterion four is met. Electronic Blocks are a resource that incorporates objects with which children are familiar. Children in early childhood education settings are familiar with blocks and other construction materials and most use them with confidence. As a result of simply playing with the Electronic Blocks, children can accidentally produce interesting behaviors that they would find fascinating.

The Electronic Blocks have inputs and outputs and when connected, the output of one block controls the input of another. Electronic Blocks can be connected together to create a wide variety of dynamic structures which interact with the environment. Different behaviors may be observed by connecting two or more blocks together. This design allows for a variety of expressive opportunities and consequently the Electronic Blocks meet design criterion one. The Electronic Blocks offer open-ended, discovery oriented learning experiences. Given a specific problem, children will be able to build, through trial and error, many different solutions. Children will be actively involved in the process of discovery.

In addition, this model of connecting blocks to create behaviors ensures that the Electronic Blocks meet design criterion six. This is a construction activity that inherently involves the design, creation, observation, use and evaluation of Electronic Block structures.

Electronic Blocks are a construction resource that provides opportunities for children to play both autonomously and actively, thus meeting design criterion two. The Electronic Blocks, like other construction material in an early childhood environment, are intrinsically motivating, process-oriented, non-literal, and enjoyable. Children are free to choose the type of Electronic Block construction activity in which they would like to take part. As such Electronic Blocks embody the fundamentals of child-initiated play.

There are three kinds of Electronic Blocks: sensor blocks, action blocks and logic blocks (see figure 1). There are three sensor Electronic Blocks: a *seeing* block, a *hearing* block and a *touch* block. These blocks are capable of detecting light, sound and touch, respectively. Action blocks produce some kind of physical output. The *light* block lights a bright incandescent bulb, the *sound* block plays a simple children's melody, and the *movement* block is a four wheel car that drives in a straight line.

Logic blocks have an intermediary role. Placed between a sensor block and an action block they have the ability to alter the expected action by altering the signal passed between blocks. Logic blocks include:

- a *not* block that inverts the sense of the signal,
- a *delay* block that prolongs the duration of the signal,
- a *toggle* block that alters the state of its signal when triggered by an incoming signal, and
- an *and* block that requires a signal on both of its inputs before passing on a signal.

Figure 1: The complete Electronic Block family: the three sensor blocks are to the left, the four logic blocks are in the centre, and the action blocks to the right.

All sensor blocks are yellow. Readily understandable icons identify the different functions of the sensing blocks: for example, an eye for a *seeing* block. The functionality of the action blocks is somewhat self-evident from the physical structure of the blocks. The *sound* and *light* blocks are also adorned with explanatory icons. Each different logic block type has distinctive icons and colors to assist their identification. It is difficult to choose meaningful icons for these blocks. What icon explains "and" to a preschooler? The icons were chosen to have readily understood adult meanings: for example, & for "and".

The blocks have been designed so visual clues are used to alert children to the block's functionality thereby assisting novices in using the Electronic Blocks. The fact that all sensor blocks are yellow and readily understandable icons identify their different functions makes the important sensor functionality easy to locate for novice block stack builders. Action blocks are self explanatory – the movement block is a car base, the light block an incandescent bulb. Such identifying features are useful in ensuring the blocks meet design criterion four.

In considering the need to provide a balance between allowing children to have opportunities to practice newly acquired skills and experience challenges just beyond the level of their present mastery, the blocks have been designed to be as flexible as possible. They provide opportunities for comfortable play experiences (the blocks can be used as ordinary blocks which can be stacked and balanced) as well as more advanced and challenging opportunities which involve creating structures that incorporate logic or interact with the environment. In using the electronic components of the blocks to create interesting dynamic structures consideration has been given to providing a number of levels at which children can work. The flexibility – with respect to skill and ability levels – with which the blocks have been designed, is a key aspect of Electronic Block design thereby meeting design criterion five.

Electronic Block Scenarios

The following illustrative scenarios were developed to outline some uses of the blocks in educational environments. They highlight the ways in which design of the Electronic Blocks fulfils the goal of being specifically suited to the developmental abilities of children aged between three and eight years of age. The scenarios are based on a set of Electronic Blocks which contains

- three sensor blocks - a seeing block, a hearing block and a touch block,
- two action blocks - a movement block and a light block, and
- one logic block - a not block.

Scenario 1: Emily's Experience

Emily is three years old. She has somewhat different physical, social, emotional, and learning needs to older children and adults. Emily has not yet developed abstract thought and intangibles beyond her immediate world are vague and unreal. She is therefore sensory dependent, needing to see and touch, to hear and feel. Emily will learn best by directly interacting with her world.

Emily likes to stack and balance the Electronic Blocks. In doing so she becomes familiar with their simple functionality. She experiences Electronic Blocks in the same manner she experiences normal construction material. As with other blocks she will progress from placing them beside one another, to putting them in containers, to creating towers by stacking them on top of one another.

Emily places at *hearing* block on a *light* block and accidentally produces an interesting behavior. She notices that the light shines whenever she talks. The light flickering as she talks makes her laugh … that makes the light shine some more! She then removes the *hearing* block and places it on a *movement* block. The vehicle moves when she talks too.

Scenario 2: Andrew's Interactions

Andrew is five years old. Cognitive development for Andrew still largely relies on the use of senses to examine and explore his surroundings. Although he is becoming more capable of concrete operations he still learns best when actively manipulating and transforming real materials.

Electronic Blocks allow Andrew, through trial and error, to build an artifact with a particular functionality. In this instance Andrew would like to move the *movement* block. He places the *touch* block on the movement block. Every time Andrew goes to pick up this vehicle it moves! Now Andrew tries placing a *not* block between the *movement* block and the *touch* block. This is a much better solution. The *movement* block moves around and only stops when Andrew touches it. This makes it a lot easier to pick up!

Scenario 3: Rachael's Experiment

Rachael is seven. She is moving from preoperational to concrete operational thought and is capable of concrete thinking in many situations. Despite her advances, she still finds learning easiest while actively manipulating real materials.

Rachael has the *hearing* block connected to the light block and is playing with this simple artifact. When she claps her hands the *hearing* block causes the light to turn on. She then places the *seeing* block on the *movement* block - nothing happens. Returning her interest to her earlier creation, Rachael claps her hands to watch the light go on. Surprise, surprise! While the light is turned on, the car moves towards it. When Rachael stops clapping the light turns off and the car stops. Rachael, fascinated continues to play with her new remote control system.

Simple Sensor-Action Block Constructions

Constructions such as those described in scenario 1 are examples of simple sensor-action combinations. Given a set of three sensor blocks and three action blocks, there are a total of nine such combinations. Figure 2 provides an example of a sensor-action combination. Initially, interactions with the Electronic Blocks may be limited to a reduced set including only sensor and action blocks. While children are becoming used to the functionality of this new resource it may be advantageous to limit interactions to simple input-output combinations.

The Impact of Logic Blocks

The addition of logic blocks to the set of Electronic Blocks opens up a wide variety of additional construction opportunities. In scenario 2, the *not* block provides Andrew with the capability to build a structure that only produces an action if a particular stimulus is not received. In Andrew's interactions with the Electronic Blocks, he worked out how to use a logic block to make his car construction more manageable.

Figure 2: A touch block attached to a light block will cause the light to turn on whenever sensor plate is touched.

Figure 3: A remote control car demonstrates interaction between block stacks. The touch block on the light block forms the remote control for the car formed by placing a seeing block on a movement block.

Increasing Complexity – Creating Interacting Electronic Block Stacks

A fascinating aspect of Electronic Blocks is their ability to interact not only with the environment but also with each other. This type of interaction is exemplified in Rachael's experiment (scenario 3). By creating one block stack which contains a *hearing* block and a *light* block and another stack which has a *seeing* block on top of a *movement* block, Rachael has effectively created a remote control car. By clapping hear hands, she triggers the light. This light in turn is detected as an input by the seeing block which actives the *movement* block. Figure 3 provides an example of interacting Electronic Block stacks.

To add further complexity logic blocks could be included in these interacting stacks. The construction opportunities offered by the full set of Electronic Blocks are wide and varied.

EVALUATION OF ELECTONRIC BLOCKS

The evaluation of Electronic Blocks within preschool and primary school classrooms was directed at assessing the extent to which Electronic Blocks are a developmentally appropriate resource for early childhood technology education. This focuses the evaluation on determining whether the children can use the Electronic Blocks easily, whether they enjoy using the Electronic Blocks and whether they understand what they were doing with the blocks.

Evaluation Methodology

The evaluation of the Electronic Blocks has been divided into two distinct studies. One study is designed for preschool children, aged between 4 and 5 years. The evaluation study for this age-group is structured in such a way as to observe the children using Electronic Blocks in a natural, open-ended, free-play setting. The second study is designed for primary school children between 7 and 8 years of age. During this study the primary school children were given time to explore the functionality of the Electronic Blocks in open-ended free play sessions before becoming involved in using the blocks to complete specific programming tasks.

Preschool Evaluation: Situated Observation of Active Thinkers

The preschool evaluation of Electronic Blocks took place at a University Campus Preschool. Twenty-eight children aged between 4 and 6 years participated in the evaluation. Fifteen of the participants were female, thirteen were male.

The study spanned two weeks. Three evaluation sessions per week were conducted and each session lasted 90 minutes. For each session the Electronic Blocks were set up in an area within the indoor play area. A video camera and audio equipment were used to record children’s interactions with the blocks. All children within the Preschool Room were free to participate in the study. However, due to the number of Electronic Blocks available, a limit of four children using the blocks at any time was imposed.

The investigator actively participated in all evaluation sessions, providing children with ideas on how they might use the blocks, answering their questions, helping them to solve problems, and encouraged working in pairs or groups. By sessions 5 and 6, the involvement of the researcher was reduced. While available to help them if they ask for assistance, the researcher did not play an active role in stimulating the children’s play experiences with the blocks.

Primary School Evaluation: Problem Solving Observations

Twelve children, aged between seven and eight years, were used for this study. They were all grade 3 students at a local primary school. The school had three classes of grade three students and four children were chosen from each class. The teachers were asked to choose average students who worked well together and to group them as pairs. Each class supplied two girls (paired) and two boys (paired).

At each session Electronic Blocks were set up in a break-out room usually used for remedial work with children. A video camera and audio equipment to record the children interacting with the blocks was set up with the aim of being as unobtrusive as possible.

The students involved in the primary school study were required in the first instance to work as one large group to participate in an Electronic Block lesson. They then participated for one session as three groups of four students in an open free play environment. The remaining sessions involved children working in pairs to complete specific tasks.

ELECTRONIC BLOCKS OBSERVATIONS

A significant portion of the Electronic Block evaluation has focused on determining the extent to which the blocks are developmentally appropriate resource for children aged between 3 and 8 years. During the evaluation children have been observed to determine how easy they found the Electronic Blocks to use and learn, the types of interactions which occurred, the minimum level of knowledge and skills required to become engaged in the blocks, how well the blocks catered the different abilities and interests and the level of enjoyment that was exhibited. By examining each of these areas, clear conclusions may be formed regarding the Electronic Block’s appropriateness.

Ease of Use and Learnability

The ease of use of the Electronic Blocks has been clearly established. Ease of use in the Preschool evaluation was exemplified by the high level of child initiated play. Given that interaction with the Electronic Blocks was optional and primarily involved free play, the high percentage of preschoolers who voluntarily played with the Electronic Blocks and returned on two or three occasions indicated that most children felt confident initiating play with the blocks. Throughout the preschool evaluation evidence showed that the “no wrong answer” design of the Electronic Blocks meant that there was no incorrect constructions – only unexpected outcomes. As a result children were able to build constructions without a great deal of intervention.

The successful and repeated construction of working Electronic Block stacks reflects the preschool children's understanding of the resource. Each child built, on average, 7 working stacks of Electronic Blocks. While one child built none, two children built in excess of 20 during a single session with the Electronic Blocks. In general the preschool children's interactions with the investigator involved asking questions when they were having difficulty understanding the functionality of a particular block. As the evaluation progressed the children developed a simple understanding of how the blocks worked and were increasingly able to initiate the construction process.

While half the primary school children acknowledged that it could be difficult the construct structures to meet particular goals, feedback from the children found that a majority of the children found the Electronic Blocks easy to use. The children's ability to stay on task, work without assistance and complete tasks support this statement. Children were more likely to stay on task, complete a task, and not ask for assistance, on the sensor action and the interacting stack tasks. While the variation isn't great, that data does show that as the tasks became more difficult and included logic blocks and logic combinations children were less likely to stay focused on completing a task without assistance.

Across the tasks primary school children were asked to complete there was strong evidence that children were able to achieve a desired task solution. Children created appropriate program stacks on their first attempt on 47% of occasions. They used trial and error to create correctly working program stacks on 35% of occasions, and had difficulty creating a working solution on 18% of occasions. As tasks became more complex, the ability of the children to find a successful solution on the first attempt decreased. Children generally found tasks which used logic blocks more difficult to solve than sensor action tasks or interaction block stack tasks. The inclusion of logic blocks in a task solution resulted in a greater number of children using trial and error to build the necessary behavior into the structure.

The concept that caused the greatest difficulty was that of inputs and outputs and the idea that the behavior of the action block is reliant on some signal from a sensor or a logic block. The input-output relationships of the blocks are not directly visible, and must be discovered by exploration to be fully understood. The signals passed between blocks are "symbols" that are not initially grasped by the young. This may account for the children's initial difficulty with this concept. Once the children understood this concept they were able to build any number of exciting creations.

The preschool children tended to build complexity into their Electronic Block structures by creating interacting block structures. With interacting block structures, input and output are visible and understandable. However, most children struggled to see how more complex and useful systems could be developed with the other logic blocks. They could not grasp the relationship between the invisible signals passed between blocks and the behaviors of the logic elements. The reliance on visible interaction between the blocks is understandable in light of cognitive models of child development that characterize a typical preoperational preschooler as sensory-dependent.

The primary school evaluation provided evidence that children's ability to create complex Electronic Block structures increased over time and through exposure. While all children demonstrated the ability to use sensor and action blocks in constructing stacks for simple tasks, improvements were seen in the children's ability to effectively use logic blocks and create complex interacting block stacks. The children generally found tasks which involved the use of logic blocks more difficult to solve than those involving simple sensor-action combinations. They subsequently found these tasks more challenging. There was evidence of improved proficiency in identifying and correctly using *not* blocks in programming tasks and similar improvements in functionality understanding were observed during the construction of task solutions that required an *and* block. A majority of the children appeared to be able to learn how to successfully use logic blocks to achieve a desired result during the course of the Primary School evaluation.

Interactions with Electronic Blocks

The evaluation of the Electronic Blocks demonstrated that the children were actively involved in meaningful construction activities. The children were able to construct a vast number of different types of vehicles, robots and other creations. Throughout the Electronic Block evaluation there was strong evidence that children were able to consistently construct working block stacks. The design of the blocks made active manipulation and transformation of real materials the basis of interactions. Concrete interactions were the primary means by which children explore the dynamic properties of the blocks.

While not all construction was understood, children displayed high levels of interest and excitement exhibited when their constructions exhibited some behavior. A majority of the children involved in the evaluation gained an understanding of the functionality of the sensor blocks and the output blocks and many developed knowledge of how the logic blocks altered behaviors as the evaluation progressed. During the preschool evaluation many of the repeat visitors developed a basic understanding of the logic blocks, with the not and toggle blocks being used extensively during the evaluation. Similarly, primary school children's ability to successfully use the logic blocks in construction activities increase with exposure to the Electronic Blocks.

Very few children exhibited signs of frustration while using the blocks. Generally frustration was caused by the blocks' failure to produce the desired outcome. In many instances this was due to a technical difficulty encountered by the child, a flat battery for example. On a few occasions the frustration was due to not understanding the functionality of the blocks. One notable episode occurred on the first day of the Preschool evaluation. Outgoing *Ro* 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”. The primary school children, through their consistently high levels of interest and attention showed that they remained engaged in construction activities even when confronted with difficulties. They were generally eager to find solutions to the problems presented.

During both the preschool and primary school evaluations children were able make discoveries about different constructions. In the preschool sessions there were many examples of children building a structure with no particular purpose in mind and then working through the process of discovering exactly what their structure “could do”. As discovered in both the preschool and primary School evaluations, many of the interactions with the blocks involved the children observing the output produced by the blocks given a specific input. This turned the children into scientists and engineers, making observations, creating studies, exploring limitations and designing new structures.

Minimum entry knowledge and experience

The preschool evaluation, consisting of young children aged between 4 and 5, is most appropriate for assessing the extent of knowledge and experience required to play with the Electronic Blocks. Of the twenty-eight children involved in the Electronic Block preschool evaluation, only two failed to gain an understanding of the functionality of the sensor blocks and the output blocks. This lack of understanding was the result of a failure to become involved in the construction process, with one of these children choosing to observe construction activities, while the other only built one Electronic Block structure. These children were content to watch other’s building with the blocks, but did not feel inclined to do so themselves. The children did not engage in the constructivist learning process, which appears the principle reason for their lack of ability with the blocks. This emphasizes the importance of engagement in developing understanding. Even so, the children participated in the social aspects of the block building group, and were content to be primarily involved in observation of activities.

The other twenty six participants happily stacked and balanced the Electronic Blocks and as a result became familiar with their simple functionality. The children experienced Electronic Blocks in the same manner they experience any other construction material. As a result of simply playing with the blocks, children unintentionally produced interesting behaviors that they found fascinating. They asked questions, used trial and error and appeared to delight in the simple behaviors they were able to produce.

It is apparent that the entry level knowledge required to use the blocks is comparable to other early childhood activities. Engaging outcomes are achievable from the simplest construction, providing opportunities for further exploration and learning.

Suitability for wide range of children

The Electronic Blocks were suitable for children with varied skill and ability levels. Evidence from the preschool evaluation showed that while some children only became familiar with simple input-output combinations, the blocks were able to provide challenges and extensions as children were prepared to explore the functionality of the logic blocks. In addition, the children tended to build complexity by creating interacting block structures.

As with the preschool evaluation, the primary school children found that while they were easily able to build simple structures, they were increasingly challenged with tasks involving the use of logic blocks. In an educational environment Electronic Block tasks would easily be tailored to the ability level of each individual student, with some students focusing on simple sensor action tasks and interacting block tasks while others complete tasks that utilize logic combinations.

The Electronic Blocks also proved suitable for children with different interests and interaction styles. During the Preschool evaluation there was significant evidence that the blocks were suitable for different interaction styles. Some children liked to create a single construction and then play with it for an extended period of time while others enjoyed the creation – and destruction – process. A small number of children were content to watch other children play with the blocks. Some children built with the express purpose of creating a particular “thing” while others were more interested in the act of construction, building great towers with the blocks. There were also examples of children using the Electronic Blocks to enhance and extend their creative and pretend play experiences.

The evaluation showed that the Electronic Blocks opened up a wide variety of interaction opportunities for children and catered for different play styles, ability levels and interests.

Enjoyment

Levels of enjoyment can be ascertained largely by positive attitudes exhibited by the children while they were using the Electronic Blocks. Within the preschool evaluation, the data on time spent playing with the blocks – an average of 15 minutes for each encounter – reflected this enjoyment. Given the age of the children, remaining interested in Electronic Block activities for an average of 15 minutes is remarkable. The average amount of time spent with the blocks over the six sessions (33 minutes) demonstrates a noteworthy level of interest in the Electronic Blocks environment, particularly when you consider that only four children could use the blocks at one time. The children remained interested in the blocks for the duration of the evaluation. A majority of the children choose to play with the blocks on more than one occasion, with most children participating in the evaluation two or three times.

As mentioned previously, the data highlighted that enjoyment was exhibited in a number of different ways as the flexibility of the blocks allowed for a variety of interaction styles. In addition, the responses by children during group time on the last day of the evaluation indicated that they found the Electronic Blocks fun to use, although 40% of the children acknowledged that they found the blocks challenging ("a bit tricky"). A noteworthy level of interest in the Electronic Blocks environment was observed over the period of the preschool evaluation. This was evident by the number of voluntary participants, the length time involved and the level of repeat visits.

When asked to comment about what they enjoyed most, the preschool children's responses entirely comprised of output behaviors the children were able to produce. They were excited about the cars they were able to make move, the remote controls that they built to do so without direct contact with the vehicle, and the torches they were able to create with a light block and some kind of sensor input. It is concluded from these responses that the children's enjoyment primarily stems from their ability to create their dynamic systems which interact with the physical world.

The primary school children demonstrated their enjoyment while using the Electronic Blocks through their positive responses to the Electronic Block challenges presented and their consistently high levels of attention, persistence and interest. There is strong evidence of children actively listening to questions and explanations – an average of 91% across available opportunities. In addition, interest in Electronic Block tasks was exhibited by the children's positive body language (85%) and positive initial responses (with both actions and words) to task challenges (100%). Attention levels during the early stages of each task were consistently high with children paying attention to task requirements as well as during the early stages of construction an average of 98% of all possible opportunities.

In response to the feedback questionnaire that asked whether they found the Electronic Blocks "fun to use" all children responded in the affirmative. All primary school participants also indicated that they liked using the Electronic Blocks. These positive statements clearly indicate that they found the Electronic Blocks enjoyable to use.

CONCLUSION

The Electronic Blocks are developmentally appropriate for children aged between 3 and 8 years. This is supported by the high level of enjoyment and engagement in the block construction tasks, and the demonstrated understanding of the blocks' functionality. The Electronic Blocks allowed children to be active participants in design and construction activities, putting children in the driver's seat by providing an open-ended, discovery-oriented vehicle with which to work. Such a process-based approach, with its emphasis on the design and production processes, is ideal for enhancing children's technological capabilities. The success of the Electronic Blocks as a tool for technology education is largely due to the consideration of important principles of early childhood development and learning within the design process.

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These will be added for the final version, but are omitted here to ensure the anonymity of the review process.

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